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Methodological analysis for assessing the relation of the energy cost with losses of water – a case study

Análise metodológica para avaliação da relação do custo de energia com as perdas de água - um estudo de caso

Análisis metodológico para evaluar la relación del costo de la energía con las pérdidas de agua: un estudio de caso

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Matheus Gonçalves Silqueira
ORCID: https://orcid.org/0000-0002-3848-3939
Universidade Federal de Itajubá, Brazil
E-mail: mat.silqueira@gmail.com
Fernando das Graças Braga da Silva
ORCID: https://orcid.org/0000-0002-3803-2257
Universidade Federal de Itajubá, Brazil
E-mail: ffbraga.silva@gmail.com
Alex Takeo Yasumura Lima Silva
ORCID: https://orcid.org/0000-0003-1883-2414
Universidade Federal de Itajubá, Brazil
E-mail: alex.takeo@uol.com.br
Cláudio Abiar Lourenço
ORCID: https://orcid.org/0000-0002-8551-0717
Universidade Federal de Itajubá, Brazil
E-mail: claudioabiar@unifei.edu.br

Abstract
The rational use of energy is being increasingly encouraged. In some countries, there are even subsidies for industries to adopt energy efficiency measures. One of the sectors with great opportunities for efficiency is sanitation, where a large part of energy consumption refers to pumping stations. The objective of this work is to demonstrate the consumption of electrical energy and possible reduction of electrical energy consumption in a sector of study of the Autonomous Water and Sewage Service (SAAE) of the municipality in the south of Minas Gerais. To determine the measures to be taken to reduce energy costs, it is necessary to perform a system diagnosis. For this, field trials were carried out. The study sector had an average expense of R$ 42,097.44/year due to water losses in the system. When considering only electricity costs, they represent 34.20% of the costs in relation to water losses (R$ 14,395.90/year). The system presented 27.73% of total water losses, an energy consumption of 0.6627 kWh/m³ only for the R3 pumping station and 1.302 kWh/m³ when also considering the Water Collection and Treatment Plant (WTP).
Keywords: Energy efficiency; Losses; Water supply system.

Resumo
O uso racional de energia está sendo cada vez mais incentivado. Em alguns países, existem até subsídios para que as indústrias adotem medidas de eficiência energética. Um dos setores com grandes oportunidades de melhoria é o de saneamento, onde grande parte do consumo de energia é devido as estações elevatórias. O objetivo deste trabalho é demonstrar o consumo de energia elétrica e possível redução do consumo de energia elétrica em um setor de estudo do Serviço Autônomo de Água e Esgoto (SAAE) do município do sul de Minas Gerais. Para determinar as medidas a serem tomadas para reduzir os gastos com energia, é necessário realizar um diagnóstico do sistema. Para isso, foram realizados ensaios de campo. O setor de estudo teve um gasto médio de R $ 42.097,44/ano devido às perdas de água no sistema. Quando considerados apenas os custos de energia elétrica, eles representam 34,20% dos custos em relação às perdas de água (R $ 14.395,90/ano). O sistema apresentou 27,73% das perdas totais de água, um consumo de energia de 0,6627 kWh / m³ apenas para a estação elevatória R3 e 1,302 kWh / m³ quando considerada também a Estação de Coleta e Tratamento de Água (ETA).
Palavras-chave: Eficiência energética; Perdas; Sistemas de distribuição de água.

Resumen
Se fomenta cada vez más el uso racional de la energía. En algunos países, incluso existen subsidios para que las industrias adopten medidas de eficiencia energética. Uno de los sectores con grandes oportunidades de eficiencia es el

saneamiento, donde gran parte del consumo energético se refiere a las estaciones de bombeo. El objetivo de este trabajo es demostrar el consumo de energía eléctrica y la posible reducción del consumo de energía eléctrica en un sector de estudio del Servicio Autónomo de Agua y Alcantarillado (SAAE) del municipio del sur de Minas Gerais. Para determinar las medidas a tomar para reducir los costos de energía, es necesario realizar un diagnóstico del sistema. Para ello se realizaron pruebas de campo. El sector de estudio tuvo un gasto promedio de R $ 42.097,44 / año por pérdidas de agua en el sistema. Al considerar solo los costos de electricidad, representan el 34,20% de los costos en relación a las pérdidas de agua (R $ 14.395,90 / año). El sistema presentó 27,73% de las pérdidas totales de agua, un consumo de energía de 0,6627 kWh / m³ solo para la estación de bombeo R3 y 1,302 kWh / m³ si se considera también la Planta de Recolección y Tratamiento de Agua (PTAR).
Palabras clave: Eficiencia energética; Pérdidas; Sistema de suministro de agua.

1. Introduction

The water supply is the primary element of an urban system. Due to the rapid urbanization and scarcity of this resource, maintaining a stable and quality water supply has become a challenge for many cities, while a large amount of water is lost from the pipes of distribution systems. The water leakage is not only a waste of water resources but also at great socioeconomic costs. According to Araujo et al. (2006) and Fontana et al. (2012), the rates of water loss in water supply systems vary from 30% to 40%. At the same time, Colombo et al. (2009), citing other authors, quantify between 9% and 30% of unaccounted water volume in Europe. Also, leaks in distribution networks can compromise the final quality of water, through the insertion of pathogenic microorganisms, especially through the occurrence of hydraulic transients, during which pressures become low and even negative (Colombo et al., 2009). These leaks increase operating costs related to water loss and extra energy consumption, also resulting in economic losses.

Generally, accounting for water losses in water supply systems occurs through water balances, where the inlet and outlet volumes are defined at different levels of the system. A classic method of water balance, based on indicators, widely accepted and used in Brazil, is that of the International Water Association (IWA), based on the document "The Blue Pages" (Lambert and Hirner, 2000) and described in detail by Alegre et al. (2004), Andrade (2016) and Fortes (2016). Real and apparent water losses are realities in today's supply systems. According to the National Sanitation Information System (Brasil, 2015), approximately 46.87% of treated water in Brazil is lost.

According to Gomes et al. (2011), the solutions found in the literature referring to the real losses caused mainly by leaks are to replace the old pipes, valves, registers, and other equipment that are part of the system, and also to improve their pumping systems to provide the necessary pressure, reducing high pressures in the network. Besides, measurement and monitoring systems to quantify and monitor water production at specific points in the network. These losses can be classified as physical or non-physical. According to Monachesi et al. (2005), pumped water supply systems that have reduced water loss will also have a reduction in electricity consumption. information crossing of the volume made available to the distribution network with the sum of the volumes calculated in the customers' meters allows, in a systematic way, to know the value of this loss.

However, the following point must be noted: not all loss is physical, that is, it can be translated as leakage or own consumption. According to Souza (2016) and Ghorbanian et al. (2017), the non-physical losses are related to the process of commercialization of the water consumed by the population through measurement errors, unregistered users, illegal connections, and a volume actually consumed and not billed. Physical losses represent the water volume lost through leaks along with the water distribution system. Water supply systems are very complex systems.

Colombo and Karney (2002) points in many places, the energy consumption resulting from pumping water has most of the operational costs of supply, and the energy wasted to compensate for leaks is associated with several environmental impacts, such as the emission of greenhouse gases, acid rain, and resource depletion. Ulanicki et al. (2000) says pressure control is an economically efficient measure to reduce leaks in water distribution systems, in addition to preventing the appearance of new leaks. Pressure management reduces the incidence of pipeline breaks, avoiding repair costs, as well as avoiding interruption of traffic on public roads and supplying customers. Referring to the analysis and hydraulic modeling of water losses, the leaks are considered demand nodes governed by pressure (Burd et al, 2012 and Cabrera et al., 2010).

Araujo et al. (2006) and Nicolini et al. (2011), suggest the use of pressure loss devices in the network, such as pressure-reducing valves (PRVs). This is the most used technological option for pressure management and leakage reduction. At first, these methods may seem contradictory in relation to the energy efficiency of the system since lower pressure losses must be sought during the design of networks and pipelines. According to Chang et al. (2018), Silqueira et al. (2021) and Silva et al. (2020), the energy consumption in the water supply systems is directly linked to the demand or consumption of water since the energy is consumed mainly in the processes of transport and distribution of water, in addition to the energy that may be needed to collect the water from its origin. This paper aims to make a study and analyze the hydraulic, mechanical, and electrical parameters of a sector of a water distribution network in the municipality in the south of Minas Gerais, under the focus of the relation of the energy cost with the water losses.

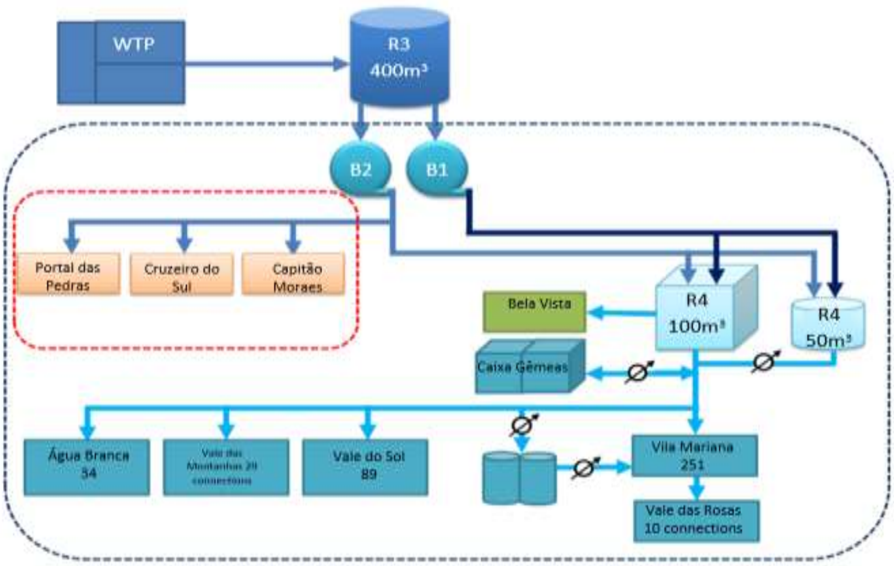
2. Methodology

Figure 1 illustrates the sector of study chosen for being an isolated sector, where it is possible to know the inputs and outputs of the system. This sector encompasses part of the area supplied by the R3 and R4 reservoirs as identified in the SAAE. It includes the neighborhoods Água Branca, Vale das Montanhas, Vale do Sol, Vila Mariana, and Vale das Rosas. The city is in the south of the state of Minas Gerais, Brazil, with a water supply system with characteristics of sectorization.

According to the National Water Agency (ANA), the city's urban water supply system draws water mostly from the Antas River, an affluent of the Itaim River, belonging to the Sapucaí River sub-basin. Another part of the water is collected at Rio do Peixe. The average volume of water collected and treated in the city is approximately 7 million liters of water per day. The treatment of the water collected from Antas River and Rio do Peixe is carried out at the same station and water treatment (WTP) and mixed in the same supply network.

The R3 reservoir (916.73m in relation to sea level) have two sets of identical pumps installed to raise the water through two isolated pipes. One of these systems pumps and directly supplies the R4 reservoir (958.73m in relation to sea level) (pipe with a diameter of 150 mm, the difference in altitude of approximately 42 meters between them, and distance of 1.41 km following the path of the pipe). The other system supplies three reservoirs that are not part of the sector of interest, namely: Cruzeiro do Sul (30 m3), Capitão Moraes (30 m3), Portal das Pedras (50 m3). The remaining flow of this pipe goes to the R4 reservoir. The study sector has a total of 413 connections. Figure 1 illustrates the design of the study sector scheme.

Figure 1 - Design of the study sector scheme.



Source: adapted from Andrade (2016).

The study sector starts in the R3 reservoir (maximum capacity of 400 m³), where part of the water is pumped through two sets of motor pumps (B1 and B2) to the R4 reservoir system, one of which is rectangular with a capacity of 100 m³ of water and is connected to a tubular reservoir with a capacity of 50 m³ of water that only begins to fill after filling the rectangular one completely (Andrade, 2016). It has 3 outlet pipes: the first supplies the Bela Vista neighborhood and this pipe connects with the 50 m³ tubular reservoir (there is a check valve before); the second pipe supplies Caixas Gêmeas (two 48 m³ reservoirs) by pumping; and the third supplies the neighborhoods of interest by gravity: Água Branca, Vale das Montanhas, Vale do Sol, Vila Mariana, and Vale das Rosas and this pipeline also interconnects with the tubular reservoir (there is a check valve before) and has dimensions of 10.4 m x 9.17 m x 1.20 m and a maximum water level height of 0.73 m, resulting in a real volume of only 69.6 m3instead of 100 m³ of its total capacity.

The cylindrical reservoir has a diameter of 3.20 m and a total height of water level of 6.20 m. The height of the useful level was defined by the position of the maximum sensor (5.92 m), resulting in a total useful volume of 47.61 m3 against 50 m³ of its total capacity. There are 2 reservoirs before Vila Mariana neighborhood, also supplied by R4, but the water from these reservoirs is only used on days of high consumption, especially during weekends. In the week of data collection, the check valve that isolates these reservoirs remained closed, isolating this part from the sector.

Through the definition of the pressure measurement location, the system analysis, and the planning of the field campaign, the team went to the city with the objective of starting data collection for seven consecutive days (October 08 to 14, 2014). The first step was to install the ultrasonic flow and pressure meters in the R4 reservoir, one in the piping that arrives from the R3 reservoir with the remaining flow after supplying neighborhoods that are not in the sector of interest and another in the outlet for the sector under study.

After the 7 days of measurement, the equipment was turned off, removed from the installed locations, and the data was stored to start the analyzes. According to Tsutiya (2001), the definition of the term water losses does not have a general and unique consensus in the world. In Brazil, these losses are calculated as the difference between the water volume produced and the water volume recorded, that is, the loss rate is the percentage of the volume produced that is not billed by the service concessionaire. The loss rate is very important, as it demonstrates the network performance. Equation 1 shows how this result can be obtained.

$$I = \frac{V_D - V_U}{V_D} \tag{1}$$

Where:

- I: Loss index;
- V_D: Distributed volume (m³) (value measured in the field);
- V_U: Volume used (m³) (Value provided by SAAE).

Thus, to estimate the value of water loss in the study sector, the following were considered:

- Distributed average flow, obtained through measurement for 07 days, equaling the monthly average;
- Average effective water consumption, obtained by measuring for 07 days, equaling the monthly average;
- Actual billed consumption, obtained from the SAAE report;
- Loss, as the difference between the distributed flow and the average effective water consumption;
- Amount of the electricity tariff, including taxes (R$/kWh), amount provided by the energy bills for the month of the field visit;
- Average electrical energy consumption of the two motor-pump assemblies of the R3 system through field measurement;

Using the percentage of water losses (Tsutiya, 2006), calculate the actual monthly energy loss from the R3 Pumping Station using Equation 2

$$Losses = I \times E \ (kWh/month) \tag{2}$$

Where:

- I: percentage of water losses;
- E: average total energy consumption of the month (kWh/month).

The monthly cost of electricity consumed in pumping the water volume lost at the R3 Pumping Station was estimated by multiplying the actual energy loss by the unit cost of energy (R$/kWh), according to the following Equation 3 (Tsutiya, 2006):

$$C = Losses \times T \tag{3}$$

Where:

- Losses: real energy losses in the month;
- T: unit cost of the electricity tariff, including taxes (R$/kWh).

The calculation of the average lost monthly volume (V_P) (m³/month) can be calculated using Equation 4:

$$V_P = (V_D - V_U) \times 30 \tag{4}$$

Where:

- V_D : distributed volume (m³/day) (value measured in the field);
- V_U : used volume (m³/day) (Value provided by SAAE).

To calculate the electricity consumption of the study sector, the proportionality ratio (Equation 5) is used, where the study sector is delimited through the numbers of connections versus the average number of inhabitants per household (connection) according to data of (IBGE, 2018). With this number of inhabitants of the study sector, it is possible to calculate

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the percentage of participation of the study sector through the total number of inhabitants of the city of study provided by (IBGE, 2018).

$$VP\ (Proportional\ Value) = NL \times \frac{NH}{NTH} \tag{5}$$

Where:

- VP: Proportional value of the study sector within the city of study through proportionality values of inhabitants (%);
- NL: Number of connections in the study sector;
- NH: Average number of inhabitants per household (connection) according to data from IBGE (2018);
- NTH: Total number of inhabitants according to data of (IBGE, 2018).

Through the sector's percentage and with monthly electricity consumption data from the collection, water treatment plant, and R3 pumping station supplied through accounts (SAAE) it is possible to calculate the monthly electricity consumption of the study sector by Equation 6.

$$CE = CAP \times VPC + ETA \times VPE + R3 \times VPR \tag{6}$$

Where:

$$VPC = {VOL\_CAP}/{VOLMED\_SETOR} \tag{7}$$

$$VPE = {VOL\_ETA}/{VOLMED\_SETOR} \tag{8}$$

$$VPR = {VOLT\_R3}/{VOLMED\_SETOR} \tag{9}$$

Where:

- CE: Electricity consumption in the study sector (kWh/month);
- CAP: Monthly data on electricity consumption in the Collection sector (water collected from rivers and directed to the water treatment plant);
- ETA: Monthly data on electricity consumption in the water treatment plant sector;
- R3: Monthly data on electricity consumption in the R3 pumping station sector;
- VPC: Proportional value of the study sector related to collection;
- VPE: Proportional value of the study sector for the water treatment plant (WTP);
- VPR: Proportional value of the study sector for the R3 pumping station.

Through monthly data of the volume in m³ of water of the sectors of collection and water treatment plant provided by SAAE and the data of average daily measurement of the volume pumped by the R3 pumping station (normalized to monthly average) it is possible to correlate the percentage of consumption participation in the study sector through Equation 10:

$$VOL\_R3 = {VOLMED\_SETOR}/{VOL\_MED} \tag{10}$$

Where:

- VOL_R3: Proportional value of the study sector within the volume of water pumped by the R3 pumping station (%);

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- VOLMED_SETOR: Data of average daily measurement of the volume consumed by the study sector (m³) (normalized to monthly average);
- VOL_MED: Data of average daily measurement of the volume pumped (m³) by the lifting station R3 (normalized to monthly average) that reaches the reservoir R4 through the pumps 1 and 2 motor sets;

The calculation of the indicator to find the electrical consumption in the production and distribution of drinking water from an SAAE (IT), can be described by Equation 11, 12, 13, and 14.

$$IT = IR3 + ICAP + IETA \text{ (kWh/m³)} \quad (11)$$

Where:

$$IR3 = {}^{R3}/_{VOLT\_R3} \text{ (kWh/m³)} \quad (12)$$

$$ICAP = {}^{CAP}/_{VOL\_CAP} \text{ (kWh/m³)} \quad (13)$$

$$IETA = {}^{ETA}/_{VOL\_ETA} \text{ (kWh/m³)} \quad (14)$$

Where:

- IR3: electricity consumption indicator at the R3 water pumping station;
- ICAP: indicator of electricity consumption in collection;
- IETA: indicator of electrical consumption at the water treatment plant;
- VOLT_R3: total water volume pumped by the two sets of R3;
- VOL_CAP: total water volume collected;
- VOL_ETA: total volume of treated water.

As the loss of water can be directly related to the loss of electrical energy, the loss of electrical energy can be calculated using Equation 15.

$$P\_EN = CE \times I \quad (15)$$

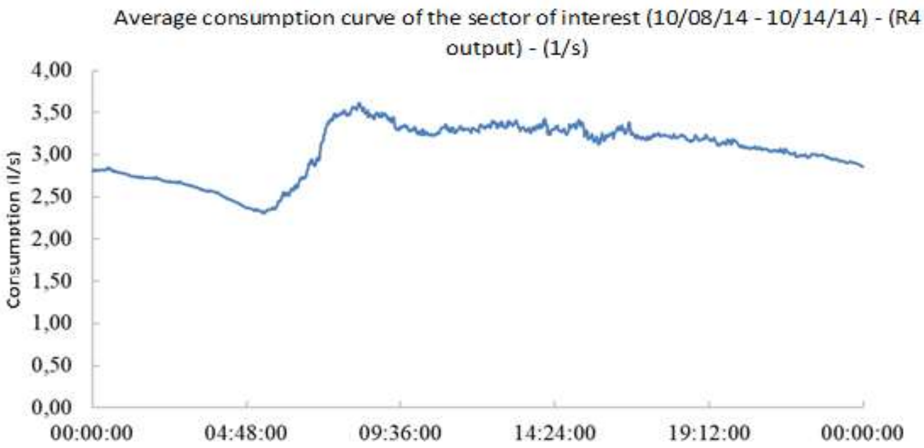
Where:

- P_EN: is the loss of electricity-related to water losses in the study sector (kWh/month);
- CE: Electricity consumption in the study sector (kWh/month);
- I: Loss index (%);

3. Results and Discussion

Figure 2 shows the average consumption curve for the sector of interest during the data collection period.

Figure 2 - Average consumption.

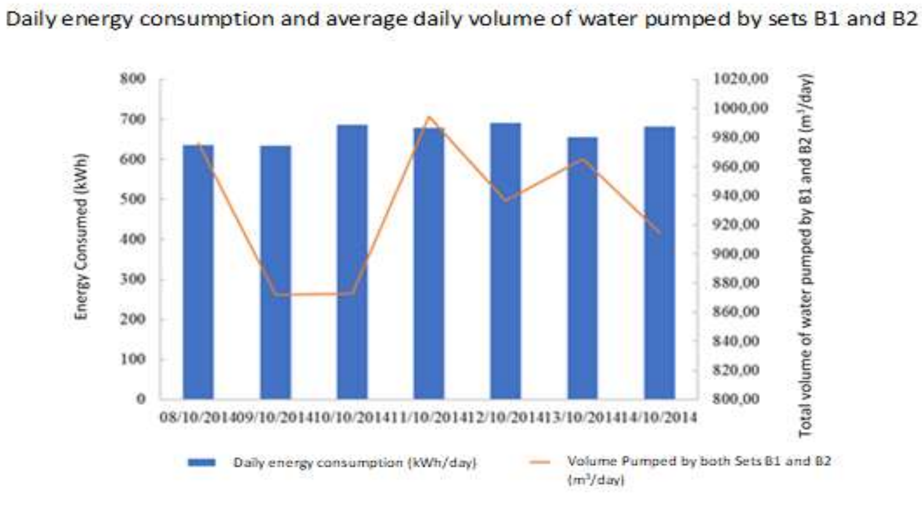


Source: Authors.

The average consumption curve of the study sector shows consumption growth starting at 7 am, and peak consumption at 8:18 am with a maximum average consumption of 3.612286 l/s or approximately 13.00 m³/h. The smallest time interval starts at 3 am until 6 am. The total average consumption of the sector of interest was 263.55707 m³/day. In October 2014, SAAE provided the value of only 5,714.00 m³/month of water billed in the study sector.

From Figure 3, we can see that Saturday was where the system had the highest flow pumped, demanding more from the system due to high consumption on weekends.

Figure 3 - Average Pumped Flow.



Source: Authors.

The study sector has a total of 413 connections. According to Instituto Brasileiro de Geografia e Estatística (IBGE, 2018), it was found that, between the 2000 and 2010 censuses, the number of people living in the same household decreased. In the period, the average number of people in each household increased from 3.79 to 3.34. Although the population has grown, the institute points out that the number of households in Brazil has increased. Therefore, for this study, 4 people were considered per connection (home/family), that is, 1652 people consume water from the study sector.

As the average water consumption in the study sector was approximately 263.557 m³/day, resulting in 0.159538 m³/day/inhabitant, or approximately 160 liters/inhabitant/day. The standard of water consumption per person, recommended by the United Nations (UN) is 110 liters per day. This per capita indicator is the amount of water sufficient to meet a person's basic daily needs. The national average is 154 liters per inhabitant per day. Therefore, we can say that the average water consumption per capita in the study sector is slightly above the mentioned values.

By calculating the Water Loss Index for the study sector, we have:

$$I = \frac{263{,}55707 - 190{,}46667}{263{,}55707} = 27{,}73\%$$

Table 1 shows the relationship between the consumption of electricity lost due to water losses in the system of the study sector. The two motor-pump sets B1 and B2 consumed 18,120 kWh/month. The study sector consumes an average of 28.93% (5,240.30 kWh/month) of the water pumped in R3, by sets B1 and B2.

Table 1 - Energy Consumption.

Energy consumption of the two Sets B1 and B2	
Relative energy consumption of the study sector (kWh/month)	**5,240.30**
Tariff in 2014, including taxes (R$/kWh)	**0.42**
Total relative energy value of the study sector (R$/month)	**2,200.93**
Lost value - R3 Pumping Station real monthly energy loss (R$/month)	**610.32**
Lost value - Actual monthly energy loss from R3 Pumping Station (R$/year)	**7,323.84**

Source: Authors.

Using the rate of the loss index of the study sector (27.73%), it is possible to calculate the real monthly energy loss of the R3 Pumping Station, resulting in the value of 1,453.1363 kWh/month, with a monthly cost of R$ 610.32/month and average lost water volume of 2,192.70 m³/month. Andrade (2016) found the value of R$ 1.60 per m³ of water collected, treated, and distributed by the AWWS of the South of Minas Gerais, including all expenses such as administrative and material. Considering this value and knowing that the average water consumption in the study sector is 263.557 m³/day, the average cost of this water is R$ 421.70/day or R$ 12,651.00/month or R$ 151,812.00/year, meaning a financial loss amount of R$ 3,508.12/month or R$ 42,097.44/year due to water losses, considering only the losses on consumption in the study sector.

The theoretical (rated) capacity of each pump is a flow of 40 m³/h and a total head of 72 m. In the field performance tests, the B1 set had a flow of approximately 37.8 m³/h. The B2 set in operation had a flow of approximately 22.7 m³/h, a value much below the rated one. However, the Average Total Flow Pumped for R4 from Set B1 was 511.6250 m³/day, an average of 21.33 m³/h, with a maximum peak of 25.10 m³/h. From Set B2 the values were even lower: the Average Total Flow Pumped was 399.8517 m³/day, an average of 16.66 m³/h, with a maximum peak of 19.75 m³/h. As the sector of interest consumed an average of only 263.557 m³/day of water, it would take only 5 hours of operation of the sets to supply the demand for water consumption in the study sector. In the campaign, it was verified that the sets were practically in operation all day. The flow Pumped only by Set B1 would supply the consumption demand of the sector under study. The system's energy savings potential can reach more than 27.73%. It was found that the flow pumped only by the B1 set is higher than that consumed by the sector, and there may be large losses of water in the distribution between R3 and R4, that is, the system appears to be oversized. There is no form of operational control to avoid triggering during the peak period. The volume of the upper reservoir is underutilized. The pump sets are operating outside the rated point. The energy-saving potential of the system can reach more than 27.73%, in the event of interventions such as those suggested.

Yields operate much below the original pump. Set B1 with 27% less and set B2 with 18% less. This makes it clear that the maintenance of the pumps has been inefficient. Insufficient pressures, when compared to the original pump, characterize that internally the pumps are defective, that is, the wear rings need to be replaced, and the rotor of each pump may be damaged or worn, and need corrective maintenance or even its replacement. As the study sector has approximately 1,652 inhabitants, the proportional value (VP) of the study sector within the city chosen through the proportionality of inhabitants is 6.2367%.

However, when analyzing the proportional value of the study sector according to the average consumption of water volume (263.55707 m³/day or 7,906.7121 m³/month), a different percentage is found for the proportional value. When considering the pumped water flow of 157,680 m³/month of abstraction and the water consumption of the study sector, there is a VP of approximately 5.02%, a value close to being compared by the population estimate. This divergence in results may occur due to the population data used or the variation in water consumption over the days of the year.

Table 2 presents the data referring to the electricity consumption of the study sector in October 2014. To make the relative calculation of only the sector of interest, the average water consumption of the sector (263.557 m³/day or 7,906.71 m³/month) was adopted.

Table 2 - Electricity Consumption.

Electricity Consumption - October 2014						
	Monthly Electricity Consumption in the Sector of Interest [kWh/month]	**Flow rate [m³/month]**	**Consumption [kWh/m³]**	**Sector Contribution [%]**	**Sector Consumption [kWh/month]**	**Sector Consumption [kWh/year]**
Collection	65,785	157,680	0.4172	5.02%	3,302.41	39,628.92
WTP	49,604	223,380	0.2221	3,54%	1,755.98	21,071.76
R3	18,120	27,344.30	0.6627	28.93%	5,242.12	62,905.44
Total	**133,509**	**408,404.30**	**1.302**	**-**	**10,300.51**	**123,606.12**

Source: Authors.

The average electricity consumption in the study sector corresponds to approximately 10,300.51 kWh/month or 123,606.12 kWh/year. The current electric tariff corresponds to R$ 0.42/kWh. Thus, the amount of energy consumed is R$ 51,914.5704. Thus, it is possible to calculate the percentage of expenses with electricity, representing 34.20%. The average cost for the production and distribution of SAAE water can be estimated using equations 16, 17 and 18:

$$Average\ energy\ cost\ \frac{index}{m^3} = IT\ \times Tariff \tag{16}$$

$$Average\ energy\ cost\ index\ per\ m^3\ = 1.302\ kWh/m^3\ \times\ 0.42\ R\$/kWh \tag{17}$$

$$Average\ energy\ cost\ index\ per\ m^3\ = R\$\ 0.548/m^3 \tag{18}$$

When considering losses in the entire supply system (SAAE), a direct relationship can be made to the water loss index. The average cost of electricity lost per m³ of water is shown in Table 3.

Table 3 - Consumption Relating to Electricity Losses - 2014.

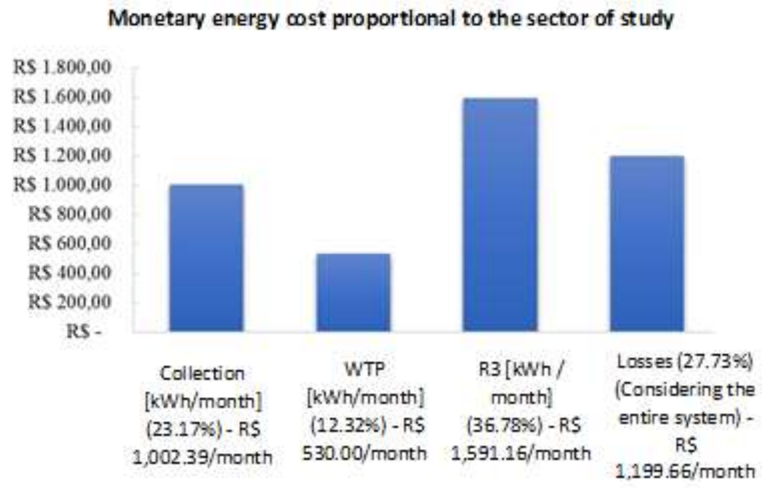
Electricity Losses - 2014 - Loss Index = 27.73%			
	Energy Losses [kWh/year]	**Electricity Losses Value [R$/year]**	**Average Cost of Lost Electricity [R$/m³]**
Collection	218,906.17	R$ 91,940.59	R$ 0.175
WTP	165,062.27	R$ 69,326.15	R$ 0.093
R3	60,296.11	R$ 25,324.37	R$ 0.278
Total	**444,264.55**	**R$ 186,591.11**	**R$ 0.548**

Source: Authors.

The cost of electricity in the water supply system of the municipality and the study sector can be represented in Figure 10, where the value of the water loss rate of the study sector in the entire system was considered. It is possible to note that the lift system is the area that consumes the most energy, followed by water losses, collection, and water treatment plant. The reduction of these water losses can bring economic benefits to SAAE and can happen through more assertive preventive maintenance, management, and planning of the pump's operating hours, avoiding excessive pressure on the nodes and possible leaks due to ruptures, replacement of inefficient pump motor assemblies, or even replacement of the piping.

Figure 4 shows the cost of electricity for each water supply system process in the study period.

Figure 4 - Monetary energy cost proportional to the study sector.



Source: Authors.

As the campaign was carried out in 2014 and until 2018, the cost per kWh/m³ increased a lot, an estimate of the population growth of the study sector was elaborated based on the estimated data of the growth of the Brazilian population (IBGE, 2018). In 2018, the estimated population for the study sector was 2,098, representing an increase of approximately 27%.

By estimating population growth and knowing that the daily water consumption per person in the study sector is approximately 0.160m³/day, it was possible to calculate the increase in water consumption in the study sector, reaching a consumption of 122,169.55 m³ of water in 2018. It is possible to notice in Table 4 that the losses only for the sector of study in 05 years can result in a high consumption of wasted electrical energy, reaching a value of 192,539.13 kWh.

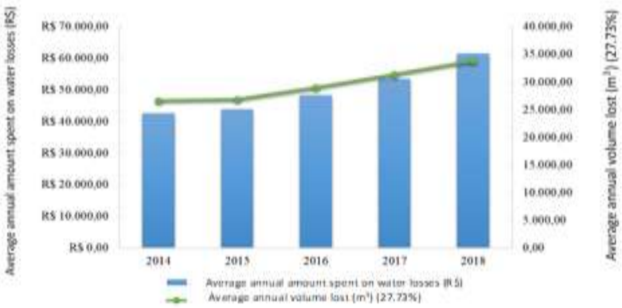
Table 4 - Relationship between the amount of energy lost due to leaks in the study sector versus estimated growth in consumption due to population growth.

Year	Average Volume of Annual Water Losses (m³) (27.73%)	Specific Energy Consumption of water (kWh/m³), the cost of energy with the Collection, Treatment Station, and Pumping Station	Amount of energy lost (kWh/year)
2014	26,675.80	1.302	34,731.89
2015	26,901.86	1.302	35,026.22
2016	29,049.49	1.302	37,822.44
2017	31,374.74	1.302	40,849.91
2018	33,877.62	1.302	44,108.66
TOTAL	**147,879.51**	-	**192,539.12**

Source: Authors.

Figure 5 represents the relationship between the volume of water lost in the study sector annually and the monetary value spent on these losses.

Figure 5 - Relationship between the volume of water lost in the study sector annually and the monetary value spent on these losses.



Source: Authors.

CEMIG provides historical data on tariffs charged per kWh, making it possible to estimate the values of the Cost Index (R$/m³), considering all SAAE expenses and the Total Average Monetary Value of Water Losses (R$). It is possible to notice in Table 5 that these losses only for the sector of study in 05 years can result in a high loss, reaching a monetary value of R$ 249,949.06.

Table 5 - Relationship of monetary value lost due to leaks in the study sector versus estimated growth in consumption due to population growth.

Year	Average Volume of Annual Water Losses (m³) (27.73%)	Specific Energy Consumption of water (kWh/m³), the cost of energy with the Collection, Treatment Station, and Pumping Station	Electricity Tariff Amount (R$/kWh) -	Energy value, considering the energy cost with Collection, Treatment Station, and Lift Station (R$/kWh)	Monetary Value of Water Losses, using the Average Energy Cost Index per m³, considering the energy cost with the collection, treatment plant, and lifting station	Cost Index (R$/m³), considering all SAAE expenses Andrade (2016)	Average Monetary Value Total Water Losses (R$), considering all SAAE expenses
2014	26,675.80	1.302	0.420	0.548	R$ 14,618.34	R$ 1.60	R$ 42,681.28
2015	26,901.86	1.302	0.44520	0.580	R$ 15,593.68	R$ 1.63	R$ 43,894.44
2016	29,049.49	1.302	0.47191	0.614	R$ 17,848.86	R$ 1.67	R$ 48,408.93
2017	31,374.74	1.302	0.50023	0.651	R$ 20,434.22	R$ 1.70	R$ 53,440.45
2018	33,877.62	1.302	0.58684	0.764	R$ 25,884.72	R$ 1.82	R$ 61,523.98
TOTAL	**147,879.51**	-	-	-	**R$ 94,379.82**	-	**R$ 249,949.06**

Source: Authors.

4. Conclusion

This paper presented a study to analyze the hydraulic, mechanical, electrical, and economic behavior of a water distribution network sector in southern Minas Gerais, under the focus of the relationship between water losses and electricity consumption.

Yields operate much below the original pump. Set B1 with 27% less and set B2 with 18% less. This makes it clear that the maintenance of the pumps has been inefficient. Insufficient pressures, when compared to the original pump, characterize that internally the pumps are defective, that is, the wear rings need to be replaced, and the rotor of each pump may be damaged or worn and need corrective maintenance or even its replacement.

In the SAAE case study, water losses can mean an economic loss of R$ 42,097.44/year. Considering a stable situation of water losses in the study sector between 2014 and 2018, these losses only for the study sector in 05 years can result in a high monetary loss of R$ 249,949.06. The study in the SAAE study sector showed that the system has a significant energy saving potential of 27.73% by reducing water loss.

The diagnosis provided by the study allows an understanding of which components are responsible for greater energy losses in the system. The high inefficiencies of pumps require reevaluating the needs of a pumping station by studying new ways to supply a given area in a less energy-intensive way or to redesign the system.

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