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ARTICLE 15

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IMPLEMENTATION OF MEASURES TO CONTROL AND REDUCE WATER LOSSES IN THE DISTRIBUTION SYSTEM OF THE BUENO DE ANDRADE DISTRICT IN THE MUNICIPALITY OF ARARAQUARA – SP

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Abstract: Water losses in distribution systems compromise the sustainability of public utilities providing this service, as well as the private sector, which has been active in this area with the aim of reducing costs. Nationally, the average total losses among water utilities range from 35% to 55%. The costs and investments required to expand the production and distribution of treated water are quite high. Consequently, companies must seek solutions to address this high level of losses. Thus, the objective of this study is to implement measures to reduce water losses in a water distribution system, specifically in the district of Bueno de Andrade in the municipality of Araraquara – SP. To this end, system operation data were monitored, such as volumes produced, volumes measured by micrometers, electricity consumption, and pressures in the distribution network, making it possible to estimate the system's loss indicators. To reduce water losses in the district of Bueno de Andrada, a methodology was proposed comprising several actions, ranging from the installation of a macro flow meter to control production; real-time monitoring of system pressures; conducting a survey for non-visible leaks; and replacing the existing fleet of velocimetric and volumetric water meters with radio-frequency volumetric meters. Following the implementation of these measures, it was found that the distribution loss rate decreased from 52% to 12%. The replacement of water meters with radio-frequency volumetric meters alone resulted in an average increase of 2.33% in the volume consumed. The installation of a new large-capacity flow meter in the production system highlighted the critical importance of properly monitoring the volume produced to ensure the reliability of this data. It is not acceptable to monitor production volume in a water distribution system based on estimates derived from the manufacturer's pump curve; measurement is necessary to maintain control. The combined actions of investigating non-visible leaks and real-time pressure monitoring help reduce physical losses in the system, making it possible to locate leaks quickly, as a system alert is triggered the moment pressures drop significantly, indicating a trend toward the emergence of a new leak. Thus, the leak detection team is immediately dispatched to locate potential leaks in the field, ensuring an immediate response time.

Keywords: Water losses. Water supply. Smart city.

INTRODUCTION

This article addresses the vital importance of water for human civilization from ancient times to the current challenges of scarcity and quality. It illustrates the discrepancy between countries with low water availability but efficient solutions, such as Israel, and countries with abundant water resources but facing problems accessing drinking water, such as Nigeria.

The study focuses on water planning and technological solutions to combat water losses, which are significant in Brazil, and their relationship to sustainable development and SDG 6. It highlights the environmental, economic, and health impacts caused by water losses and the importance of combatingthem to ensure access to drinking water for the population and contribute to reducing water losses in Araraquara and Bueno de Andrade, transforming the cities into "smart cities" with efficient water resource management, increasing the revenue of the Araraquara Autonomous Water and Sewage Department, and serving as a model for other areas of water control and management.

OBJECTIVES

The objective of this study is to implement measures to reduce water losses in the distribution system of the Bueno de Andrade district in the municipality of Araraquara, São Paulo.

- Characterize the water distribution system of Bueno de Andrada;
- Survey and quantify, using indicators, the actual and apparent losses in the water distribution system;
- Propose methodologies for administrative and practical actions to control losses.

METHODOLOGY

The methodology presented in this research study encompasses a case study based on a pioneering initiative by the Araraquara Water and Sewerage Authority (DAAE), which seeks to explore innovative approaches in the field of sanitation, specifically in water loss management. In this case study, the adopted methodology involves integrating smart city concepts into the challenging context of this project.

The study was conducted in a real-world environment, taking into account demographic data, the number of households, and the system's initial consumption levels. Real-world data collection took place from February 2021 to October 2022, totaling 21 months of data collection and implementation of the proposed strategies.

To facilitate visualization and understanding of the process, a flowchart (Figure 1) was developed to illustrate the stages and key elements involved in the study. The flowchart presents the sequence of activities and the interactions among the project components, providing a clear overview of the development of the loss management study.

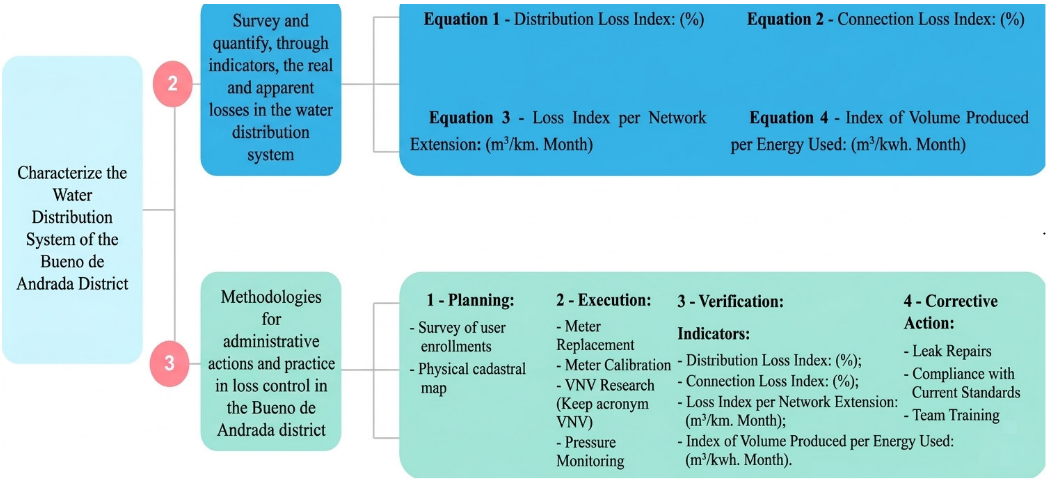

Figure 1: Flowchart of the methodology developed for loss management actions in the District of Bueno de Andrada

Source: The Author, 2023.

CHARACTERIZING THE WATER DISTRIBUTION SYSTEM OF BUENO DE ANDRADA.

To characterize the water distribution system of the Bueno de Andrada District, field visits were conducted to survey (physical characteristics) the following points of the local water supply system:

- water production point, consisting of an underground intake;
- water distribution reservoir;
- distribution networks;
- sub-metering.

In addition to the field survey, the Autonomous Department of Water and Sewage (DAAE) was also asked to provide the designs for the implemented infrastructure, such as the well, the reservoir, and the distribution networks.

Survey and quantify actual and apparent losses in the water distribution system using indicators

To control losses in a water supply sector, it is essential to adopt indicators that allow for the implementation of preventive and corrective measures.

To obtain the data necessary for calculating the indicators, the following procedures are carried out:

- initially, an email was sent to the Commercial and Institutional Relations Directorate of the Autonomous Department of Water and Sewage (DAAE) explaining the scope of this study, for which it was necessary to obtain the required information, such as:

1) volume of water distributed for the years 2021 and 2022;

2) volume of water measured by micrometers for the years 2021 and 2022;

3) number of connections and existing savings in the micrometered network for the years 2021 and 2022;

4) network length for the years 2021 and 2022;

5) energy consumption in the water production system for the years 2021 and 2022.

- Using the data provided by the Loss Control and Energy Efficiency Department, it was possible to tabulate this information in a spreadsheet and apply the formulas described in Equations 01 through 04;

Equation 1 - Distribution Loss Index: (%)

$$IP = \frac{Vma - Vmi}{Vma} \, x \, 100$$

Equation 2 - Loss Index per Connection: (%)

$$IP\ lig = \frac{Vma - Vmi}{nlig}$$

Equation 3 - Loss rate per network length: (m^3/km·month)

$$IP\ ext = \frac{Vma - Vmi}{ext}$$

Equation 4 - Volume index per unit of energy consumed: (m^3/ kWh·month)

$$Vol\ energ = \frac{Vma}{energ}$$

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Where:

Vma = gross measured volume ($^{m^3}$);

Vmi = micrometered volume (m^3);

nlig = number of connections per month;

ext = length of water network in km;

energ = energy used in kWh per month.

Methodologies for administrative and practical actions to control water losses in the district of Bueno de Andrada

The PDCA methodology was applied to develop this administrative action, involving four stages: planning (*Plan*), execution (*Do*), verification (*Check*), and corrective action (*Act*), with the aim of achieving continuous process improvement.

The Bueno de Andrada district was chosen as the case study due to the similarity between its water supply system and that of a measurement and control district (DMC) in the city of Araraquara.

In this case, Bueno de Andrada has a single water intake, and therefore a single supply system, consisting of a well, a reservoir, and a distribution system.

-Planning (*Plan*): To survey user registrations, we used the database available in the GSAN program, which is software used to manage information related to water supply and basic sanitation services. The database can be accessed by entering user registration information, such as name, address, CPF, and email, as shown in Figure 2.

After identifying the users' registration numbers in the GSAN program, a process of verification and validation of the registration information was carried out. To this end, an *on-site* inspection was conducted in the presence of a DAAE meter reader to analyze whether the commercial registration report was complete and whether there were any inconsistencies regarding the users' registration, as shown in Figure 3.

- Execution, Implementation (*Do*): Following the action plan, water meter replacements were carried out, with this phase taking approximately five months. The extended timeframe is justified because it is known that water meter replacements always generate complaints within the community; furthermore, per guidance from the DAAE Board of Directors, the work had to be carried out in a staggered manner on a monthly basis from April to August 2021.

The previously installed water meters were multi-jet, velocimetric, and volumetric types, mounted on stands or in standard DAAE boxes ( ). All 112 existing water meters were replaced with Altair-brand volumetric water meters manufactured by *Diehl Metering*, equipped with radio frequency modules for remote data transmission, as illustrated in Figure 4.

Figure 4: Image of the water meter installation in a double box in the Bueno de Andrada District

Source: The Author, 2023.

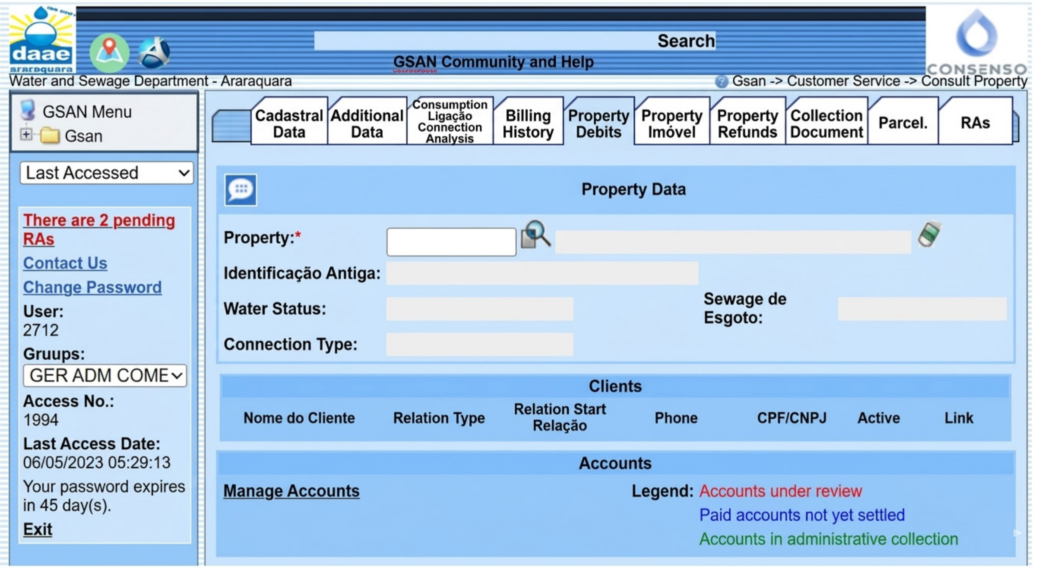

Figure 2: GSAN Program's initial data entry screen

Source: The Author, 2023.

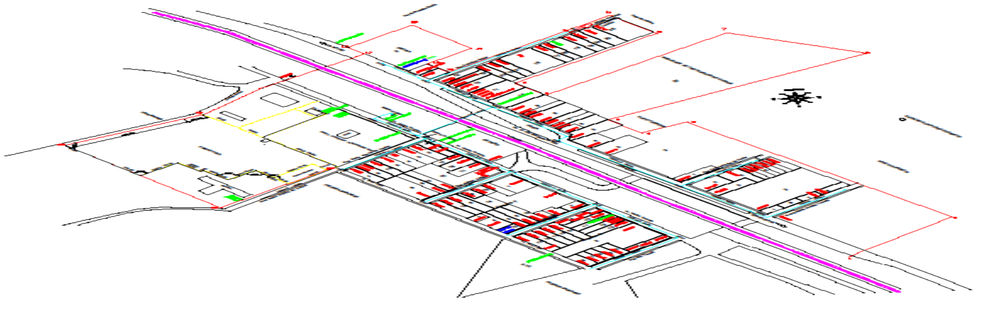

Figure 3: Registration Map of the Municipality of Bueno de Andrada

Source: DAAE Engineering Department (2023).

Initially, out of the 112 meters removed, 10 flow meters and 68 volumetric meters were randomly selected according to their metrological class and sent to the DAAE calibration bench, with a report from Inmetro.

During this period, investigations of non-visible leaks (NVR) were also conducted, using listening rods and electronic geophones.

- Verification (*Check*): Here, it is very important to use appropriate indicators and metrics, establishing clear goals and defining procedures for data collection and analysis.

Thus, the indicators used are:

- Distribution loss rate: (%);

- Loss rate per connection: (%);

- Loss rate due to network length: (m^3/km·month);

- Volume-to-energy ratio: (m^3/kWh/month).

- Corrective Action (*Act*): In this stage, corrective actions are implemented based on the results of the previous stage to address identified issues and ensure continuous process improvement; in other words, this is crucial for enhancing system efficiency and reducing the loss rate.

Some actions that can be taken:

- repairing leaks, if leaks are identified in the distribution networks and branches;

- replacement of faulty equipment in communication systems;

- implementation of new monitoring and control technologies;

- compliance with current regulations;

- training the team responsible for system management, ensuring the efficiency and effectiveness of the supply system.

Prior to June 2021, until the effective implementation of visualization and readings by the DAAE Operational Control Center, the master meter was not read with the correct monthly frequency, and the data recorded was always based on the hours the well was in operation, as measured by a hour meter installed on the well panel, and the well's flow rate was estimated based on the most recent pitometer reading, which often lacked monthly consistency.

Figure 5: Area of the Bueno de Andrada District

Source: Adapted by the author, Digital Globe image (Google Earth, 09/23/2022).

Thus, production data through June 2021 were calculated and estimated by multiplying the hours worked by the flow rate estimated from the pitot tube measurement.

RESULTS AND DISCUSSION

Bueno de Andrada, shown in Figure 5, is a district in the municipality of Araraquara. It has basic infrastructure, such as schools, churches, local businesses, and essential services, meeting the needs of both residents and visitors.

According to the 2010 census, the district of Bueno de Andrada has a total population of 1,695 inhabitants, of whom 242 reside in the urban area.

CHARACTERIZING THE WATER DISTRIBUTION SYSTEM

The water supply system of the Bueno de Andrada district consists of several components that ensure an adequate water supply for the population. These components include, as shown in Figure 6:

1. Groundwater abstraction: This abstraction is carried out in accordance with established regulations and standards to ensure water quality.

2. Main meter frame: This equipment is responsible for measuring the volume of water consumed by users.

3. Reservoir: This reservoir has a storage capacity of 30 m³ of water. It plays an important role in stabilizing the water supply, ensuring a sufficient reserve to meet the population's demand during periods of peak consumption or in cases of temporary supply interruptions.

4. Distribution Networks: These networks are composed of different materials, such as cast iron and PVC, and have varying diameters, ranging from 32 mm to 100 mm. However, approximately 90% of the total length of the networks consists of pipes with a diameter of 50 mm.

The system is visualized at the DAAE Operational Control Center, as shown in Figure 7. This visualization system is part of the Internet of Things (*IoT*), which describes a network of physical objects embedded with sensors, software, and other technologies designed to connect and exchange data with other devices and systems over the internet, forming part of the smart city initiative implemented in July 2021.

Surveying and quantifying actual and apparent losses in the water distribution system using indicators

During the months leading up to and during the initial implementation of the project in the district of Bueno de Andrada, various indicators were monitored that provided preliminary information on the performance of the water supply system. These indicators are presented in Table 1.

In addition to these indicators, indices related to water losses in the distribution system were also calculated, according to equations 1, 2, 3, and 4:

Measures Implemented to Reduce Water Losses

Replacement of Water Meters

From February 2021 to September 2021, water meters were replaced in accordance with technical guidelines established in collaboration with DAAE management.

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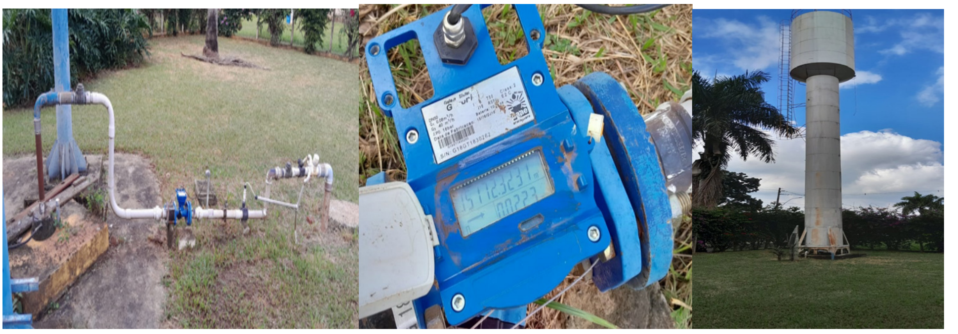

Figure 6: Image of the well, trestle, macro meter, and 30 m³ bowl-type reservoir, empty column

Source: The Author, 2023.

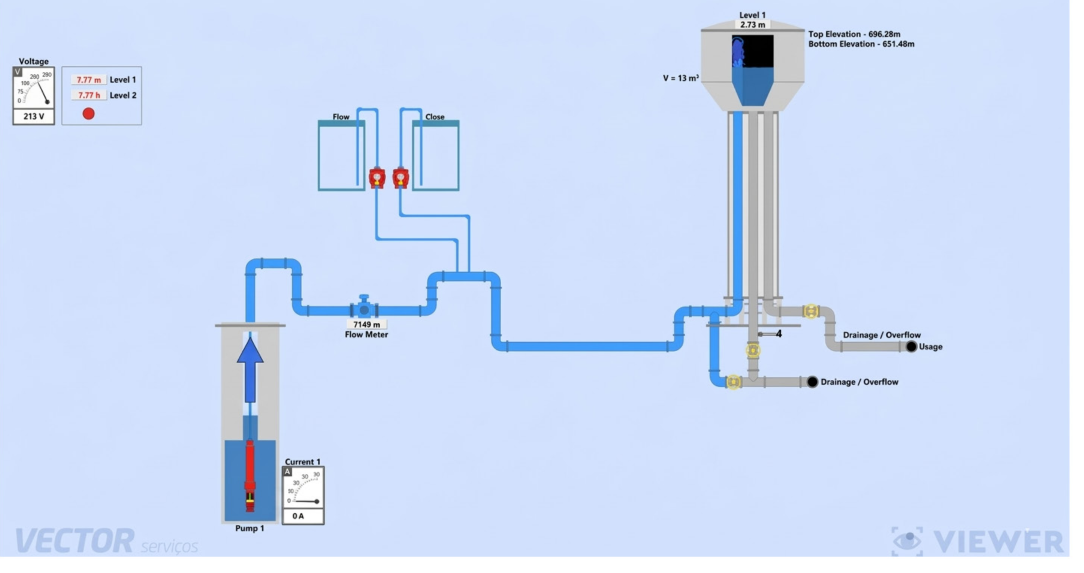

Figure 7: Screen showing the Bueno de Andrada production and reservation center in the CCO system

Source: The Author, 2023.

It was determined that these replacements should be carried out in phases. Throughout this study, the collected data and evidence were thoroughly analyzed.

Calibration of Replaced Water Meters in the Laboratory

Of the 112 water meters removed from the metering network in the district of Bueno de Andrada, a sampling process was conducted in which 78 water meters were selected for calibration. Among these, 10 were of the velocimetric type and 68 of the volumetric type. These water meters were placed on the DAAE calibration bench.

Table 2 shows the number of water meters selected for calibration on the calibration bench, classified by metrological class, along with information on whether they passed or failed.

Replacement of the macro flow meter

Figure 8 shows a decrease in the gross-measured volume from February 2021 to June 2021 and in the subsequent periods through August 2022. It is important to note that during this same period, no leaks were identified in the network or service lines, nor was there an increase in the net-measured volume.

Previously, the gross-measured volume was calculated using the well flow rate, determined via pitot tube, multiplied by the number of hours the well was in operation, as recorded on the panel's hour meter. However, it was realized that this process was incorrect. To correct this situation, starting in July 2021, the measurement provided by a water meter installed at the well outlet began to be used.

This change in the measurement method was a significant result of the project's implementation, since the measurement equipment already existed but was not being used correctly. With the proper use of the macrometer, it became possible to obtain more accurate and reliable information about the volume of water distributed by the system.

Real-time pressure control and detection of hidden leaks

The Bueno de Andrada District is an example of the implementation of a Smart City model, which seeks to improve the quality of the water distribution system. In this regard, real-time monitoring of the entire system is adopted, ranging from groundwater abstraction to the distribution stage. To enable this efficient monitoring, a process is carried out to integrate the commercial system's database with water meter measurement equipment that can be accessed remotely.

With this real-time monitoring system and data integration, it is possible to identify consumption patterns, detect leaks, monitor reservoir levels, and take preventive actions more quickly and efficiently. This approach helps improve the efficiency of the water distribution system, reduce losses, and ensure an adequate supply for the population.

A smart city, or as in the model presented, a smart district, using advanced communication technology to alert to problems in its supply system, integrating data collected by both commercial and operational systems can and should be used to improve decision-making related to the water production and supply system, implementing effective solutions to improve system quality, utilizing functional requirements to

Indicator	Month / Year				
	02/21	03/21	04/21	05/21	06/21
Volume Micromeasured (m^3)	1640	1419	1732	1856	1889
Volume Macromeasured (m^3)	2961	3148	3820	3947	4460
Pluviometric Index (mm)	151.70	70,10	28,70	20,10	33,50
Energy Consumption KWh	1143	1132	1418	1485	1678
Invoice Value R$	774,65	767,87	959,55	1120,24	1381,81
Flag	**yellow**	**yellow**	**yellow**	**yellow/red P1**	**red P1 and P2**
Distribution Loss Index (%)	44,61	54,92	54,66	52,98	57,65
Loss Index per connection (m^3/conn.month)	11,79	15,44	18,64	18,67	22,96
Loss Index per network extension (m^3/km month)	644,39	843,41	1018,54	1020,00	1254,15
Index of volume produced per energy used m^3/kwh. Month	2,59	2,78	2,69	2,66	2,66

Table 1: Preliminary Initial Project Data

Source: The Author, 2023.

	Water Meters	Type	Approved	Rejected
Removed	112			
Sampling	78			
	10	velocity	5	5
	68	volumetric	66	2

Table 2: Sample of calibrated, approved, and rejected water meters by type

Source: The Author, 2023.

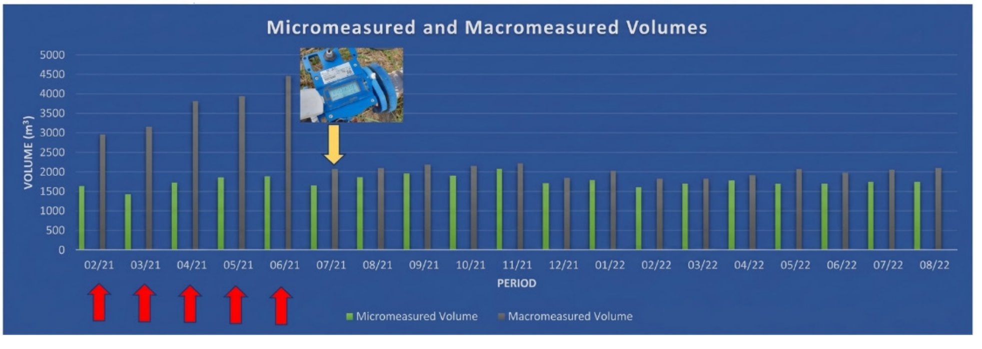

Figure 8: Micro- and macro-measured volumes for the Bueno de Andrada District

Source: The Author, 2023.

facilitate the development of applications such as:

- performing data management to enable collection, storage, analysis, and visualization, allowing for the generation of reports;

- managing sensor networks on devices installed in the district, allowing for the addition and removal of devices, monitoring, and data collection;

- processing data in applications that can run on devices with limited processing power, using both historical data from the database and real-time data;

- accessing data through an external interface using software accessible via the internet.

The definition of the smart city model used in the district of Bueno de Andrada focuses on utilizing static aspects of the city, such as maps, cadastral plans, street locations, georeferenced water meters, and integration of commercial databases with production data, complemented by dynamic aspects such as reservoir levels, distributed flow, and 24-hour online network pressure, as shown in Figure 9, and the real-time operational status of sanitation equipment.

By measuring pressure in the distribution network in real time, it is possible to obtain accurate data on pressure fluctuations throughout the day at different points in the network. This makes it possible to identify areas with excessive or insufficient pressure, which can lead to leaks, pipe breaks, and water waste.

In addition, monitoring pressure in the distribution network allows for the identification of consumption and demand patterns over time. With this information, it is possible to adjust system operations—such as scheduling pumping times—to more efficiently meet users' needs and prevent waste.

Practical experience has shown that measuring network pressure and managing the system based on this data yields significant results. This approach allows the Hidden Leak Detection team to be deployed more quickly, as a drop in network pressure is an indication of a possible water leak in the area. In addition, the use of listening rods and geophones enables the precise location of the hidden leak, allowing repair teams to be dispatched more quickly.

Water Loss Indicators Following the Implementation of Measures

Consumption data from micro-meters by account play a crucial role in calculating the indices presented in Table 3.

This data allows for monitoring consumption variations over time, as well as identifying possible correlations with external factors, such as the season and rainfall levels.

Table 4 presents the indicators calculated from the collected data.

These indicators provide important information about water losses in the distribution system and the efficiency of energy use in the supply process.

Figure 10 shows a reduction in the loss index following the implementation of two measures: the correction of well volume measurement through the use of an appropriate water meter and the installation of water meters with improved technical specifications, including radio frequency technology.

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Indices	Month / Year																		
	02/21	03/21	04/21	05/21	06/21	07/21	08/21	09/21	10/21	11/21	12/21	01/22	02/22	**03/22**	**04/22**	**05/22**	**06/22**	**07/22**	**08/22**
Metered Volume (m^3)	1,640	1,419	1732	1856	1889	1651	1854	1966	1902	2082	1715	1785	1599	1689	1773	1699	1692	1740	1746
Macro--measured Volume (m^3)	2,961	3,148	3,820	3,947	4460	2082	2098	2188	2162	2224	1837	2034	1825	1817	1919	2080	1981	2059	2089
Rainfall Index (mm)	151.70	70.10	28.70	20.10	33.50	12.70	4.40	19.00	77.66	130.20	155.50	243.30	84.00	97.50	61.00	47.00	10.10	11.20	9.80
Energy Con-sumption kWh	1143	1132	1418	1485	1678	783	789	824	813	836	691	765	686	683	721	782	745	774	785
Invoice Amount R$	774.65	767.87	959.55	1,120.24	1,381.81	645.05	650.01	677.89	894.53	920.18	760.06	841.75	755.06	751.78	793.98	666.83	635.09	660.09	669.72
Flag	yellow	yellow	yellow	Yellow/ red P1	Red P1 and P2	Red P2	Red P2	Red P2 and Water School	Water School	Water School	Water School	Water School	Water School	Water Supply	28 days Water School	Green	Green	Green	Green

Table 3: Totals for volumes, energy consumption, and bill amounts during project implementation

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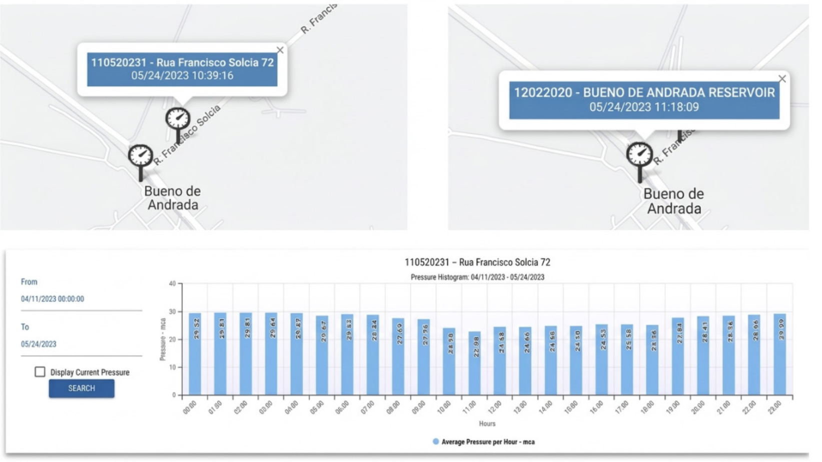

Figure 9: Pressure control point in the distribution network

Source: The Author, 2023.

Indicator	Month / Year																		
	02/21	03/21	04/21	05/21	06/21	07/21	08/21	09/21	10/21	11/21	12/21	01/22	02/22	03/22	04/22	05/22	06/22	07/22	08/22
Distribution Loss Index (%)	44,61	54,92	54,66	52,98	57,65	57,60	10,70	10,15	12,03	6,38	6,88	12,24	12,24	7,04	7,61	18,32	14,59	15,49	16,42
Loss Index per connection (m^3/conn.month)	11,79	15,44	18,64	18,67	27,96	3,85	3,85	1,98	2,82	1,77	1,09	2,22	2,22	1,14	1,30	3,40	2,58	2,55	3,06
Loss Index per network extension (m^3/km month)	644,39	843,41	1018,54	1020,00	1254,15	210,24	119,02	108,29	128,83	69,57	59,51	121,46	110,24	62,44	71,22	185,55	140,98	155,61	167,22
Index of volume produced per energy used m^3/kwh. Month	2,59	2,78	2,68	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66	2,66

Table 4: Indices, according to equations 1, 2, 3, and 4 during project implementation

Source: The Author, 2023.

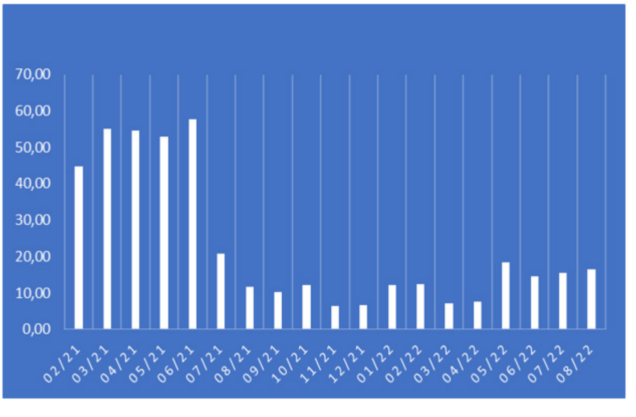

Figure 10: Distribution loss rate

Source: The Author, 2023.

The installation of water meters with improved technical specifications, including radio frequency technology, also played an important role in reducing losses. This technology allows for effective and accurate meter reading without relying on estimates or consumption averages. As a result, billed volumes became closer to users' actual consumption, preventing under-billing and ensuring fairer charges for the water supply service.

These combined actions resulted in a decrease in the loss rate, indicating an improvement in the efficiency of the supply system. Furthermore, the increase in consumption volume reflects the correction of a previous issue, where prolonged periods of billing based on averages resulted in billed volumes lower than actual consumption. Therefore, the use of accurate water meters and effective radio-frequency reading were fundamental to improving loss management and ensuring more accurate and fair billing for consumers, as shown in Table 5.

The results obtained from the project carried out in the District of Bueno de Andrada demonstrate significant effectiveness in reducing the water loss rate; an average loss of 52.96% was observed prior to the implementation of the proposed measures. Currently, this rate has stabilized at 12.26%, representing a considerable reduction in water losses.

The remaining rate of 12.26% still leaves room for improvement in loss management. These losses may be related to various factors, such as unidentified leaks, illegal connections, or metering issues. To further optimize loss management, it is essential to adopt additional strategies, such as leak detection and repair programs, awareness campaigns on responsible water use, and continuous monitoring of the supply system.

It is also important to note that, according to Inmetro Ordinance No. 246 (2000) on water meter calibration, the maximum permissible error is 10% at the minimum flow rate. This means that measurements taken by water meters may have a margin of error of up to 10% relative to the actual water consumption value. Therefore, it is essential to take this margin of error into account when interpreting the results obtained in the project

CONCLUSION

The study highlights the importance of loss management integrated into the smart city concept in the sanitation sector.

It was found that losses can occur at different stages of the sanitation project cycle, and therefore, continuous monitoring is essential. Constant analysis, reassessment, and correction are necessary to ensure that the loss rate does not rise and spiral out of control.

The team's involvement and understanding of the process's minimum parameters are essential for the effectiveness of future ongoing actions. Furthermore, it is important to foster a culture of awareness and commitment to loss reduction among all stakeholders. The continuous process requires a constant commitment from all parties.

A wide range of loss management strategies, incorporating the concept of a smart city, has been investigated. This includes the use of advanced technologies, such as micrometering, control and operation of the production and storage system, as well as real-time network pressure analysis. These technologies improve the accuracy and

Period	Measured Consumption m³	Billed Consumption m3	Period	Measured Consumption m3	Billed Consumption (m³)	Period	Measured Consumption m3	Billed Consumption m3
Jan/20	1548	1681	Jan/21	1,646	1654	Jan/22	1691	1691
Feb/20	1356	1364	Feb/21	1640	1723	Feb/22	1512	1512
Mar 20	1570	1596	Mar/21	1419	1502	Mar/22	1597	1597
Apr/20	1808	1905	Apr/21	1732	1740	Apr/22	1702	1702
May 20	1406	1521	May 2021	1856	2279	May 22	1640	1640
Jun/20	1689	1777	Jun/21	1889	2665	Jun/22	1634	1634
Jul/20	1458	1543	Jul/21	1651	1732	Jul/22	1663	1663
Aug/20	1624	1706	Aug/21	1854	1979	Aug/22	1693	1693
Sep 20	1713	1812	Sep/21	1966	2062	Sep/22	1788	1788
Oct/20	1988	2075	Oct/21	1902	1902	Oct/22	1789	1789
Nov 20	1770	1856	Nov/21	1802	1802	Nov 22	1627	1627
Dec 20	1725	1809	Dec/21	1634	1634	Dec/22	1788	1788
	Implementation period for the RF volumetric water meter system							
	RF – radio frequency							
Summary								
Total	19,655	20,645	Total	20,991	22,674	Total	20,124	20,124
Volume increase between 2020 and 2022 with			radio-frequency volumetric water meters: 2.33%					

Table 5: Comparison of measured consumption and billed consumption

Source: The Author, 2023.

monitoring of the progress of these actions. Furthermore, the adoption of quality management systems has also proven effective in reducing losses and enhancing the effectiveness of the adopted smart city model.

Based on the results and discussions presented in the study, it is evident that loss management integrated into the smart city concept is a vital area for the economic survival of water departments and, more importantly, for the survival of humanity and the environment, ensuring the rational use of water and energy efficiency.

It is recommended that the methodology discussed be implemented in other sectors, subsectors, and measurement and control districts (DMC) of the city of Araraquara, with a focus on the practical implementation of the strategies discussed in this research. Furthermore, it is necessary to develop a smart city approach using innovative technological tools, such as 24-hour monitoring of user consumption, which alerts users the following day to the likelihood of a leak in their residence, enabling faster action for repairs and preventing waste on the user's part. Identifying and resolving problems early ensures compliance with current standards and regulations.

The replacement of water meters with radio-frequency water meters has proven effective in ensuring consistency between measured and billed consumption, preventing billing discrepancies and the need for bill corrections for users. These changes, implemented via radio frequency, eliminate the need for meter readers to enter residences, improving the effectiveness, ac completeness, and security of metering. This implementation resulted in a 2.33% increase in actual consumption volume.

Overall, the study reinforces the importance of effective management, utilizing technologies within the smart city framework. It highlights the opportunities and challenges faced in this context. With the implemented measures, the distribution loss rate decreased from an average of 52.96% in 2021 to an average of 12.26% in 2022.

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