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Water Losses Assessments to support decision making in Water Supply System management

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Abstract: In order to reduce costs related to water supply service, modernization measures should be carried out to water losses. The paper presents an analysis and assessment of water losses carried out based on data provided by a water utility company. The basic indicators of water loss according to the International Water Association were then determined, such as: the leakage percentage (LP), the real leakage balance (RLB), the unavoidable annual real losses (UARL), and the infrastructure leakage index (ILI). On the basis of the categories given by IWA, we can see that the analysed water supply network is classified as a network of very good technical performance. The obtained water loss indicators in the examined water supply system (WSS) are comparable to the indicators in other collective water supply networks in Poland.

Keywords: water supply system (WSS), water losses, water losses indicators.

1. Introduction

Leakages in water networks are an objective reality that must be limited consistently and methodically. Water supply companies keep statistics of failures in the water supply network. It is then possible to assess the leaks (Alegre et al., 2016; AWWA, 2011). According to the revised Water Directive (2020/2184) and guidelines (EN 15975/1/2, 2011, 2013; WHO, 2011), the water companies have to analyse water leakage levels, using the infrastructural leakage index (ILI) rating method or another appropriate method.

Water losses in water supply systems are mainly due to pipes failure mechanisms resulting leakage. Failure mechanisms may be material defects causing damage to pipes and fittings or operation conditions such as frequent pressure fluctuations and water hammer phenomena. Modernization, renovation, and expansion activities may equally be the origin of pipes failure mechanisms (Młyński et al., 2021; Pietrucha-Urbanik, 2012; Tchórzewska-Cieślak et al., 2018).

Actual water losses mainly consist of leaks from the external water supply system to the ground and water lost during failure of pipelines and fittings. However, some apparent losses may result from inaccurate and non-simultaneous measurements balance of water supply and water consumption.

The consequences of leaks in the water supply system are twofold: direct and indirect. Direct consequences are the loss of water as a commercial product and the possibility of contamination of tap water. Indirect ones are the possibility of subsidence of the ground surface, threating the safety of pedestrian and vehicle traffic, and infiltrating the building foundations and other underground structures (Parka et al., 2019; Pietrucha-Urbanik et al., 2021; Rak & Pietrucha-Urbanik, 2019; Urbanik et al., 2019).

From the point of view of consumers and water producers, the consequences of a damage of water pipes will depend on the damage size, its frequency, its duration and the operational conditions in place. From the producers' point of view, water losses due to the so-called hidden failures are important, as well. Additional losses are due to the necessity to flush the pipelines after its repair (Pietrucha-Urbanik et al., 2021).

The main causes of damage in the water supply network are as follows (Rak et al., 2019):

- transverse and longitudinal cracking in pipelines,
- joint leaking,
- degradation of fittings,
- others.

The following failure rates are determined for individual pipe types in the water supply network (Rak et al., 2019):

- transit and main pipes: 0.3 no. of failures/km/year,
- distribution pipes; 0.5 no. of failures /km/year
- connections; 1.0 no. of failures /km/year.

The analyses of water losses in the water supply system show a level of approx. ten percentage of the daily production, compared to other cities for which the indicator is even 40%.

The aim of the study is to analyse and evaluate water losses in the Subcarpathian city water supply during the observation period of ten years.

2. Methods and output data

The network services a city with approximatively 180,000 inhabitants. The modernisation and the expansion of the network are constantly ongoing activities.

Within ten years of these activities, the network expansion is expressed by an increase of 500 metre in the mains, 185 km in the distribution pipes and 45 km in the connections. Besides, 65% of the network pipes are now made of plastics, mainly PVC and PE. Taking into account the operation time, approx. 50% of the network was built 25 years ago.

Water pipes' failure is one of the most important indicators used to evaluate the technical state and the operational conditions of the water supply network (Mays, 1998). In the technical literature, this most used indicator is the failure rate and expressed in the number of failures per one kilometre of water pipes throughout one year using the formula (Kwietniewski et al., 1993):

$$\lambda = k/(L \cdot \Delta t), \qquad (1)$$

where:

λ	–	failure rate, [no of failure/km/year],
k	–	the total number of failures per type of pipes, [no of failures],
L	–	the total length of the given type of pipes, [km],
Δt	–	the unit of time, [year].

It is worth recalling that the use of such formula implies that the failures occur uniformly over the observed time-interval and the observed length of pipes.

When analyzing water consumption by consumers, several accounting periods are compared, thanks to which it is possible to detect certain irregularities that may indicate incorrect measurements or water losses (Dohnalik & Jędrzejewski, 2004; Ociepa et al., 2019; Rak & Tunia, 2012).

It is then helpful to develop water loss indicators, the calculation of which requires the following values:

- water introduced to the network,
- own consumption,
- sold water,
- water sold for household needs,
- water losses,
- network lengths,
- number of water supply connections - LPW.

Indicator analysis of consumption and water loss in water supply system allows to obtain detailed picture of the water distribution system also the calculation of the standardized indicators allows comparisons between the water distribution systems in the cities of similar size and diverse technical condition of water supply systems (Hirner & Lambert, 2000; Lambert, 1994).

Proper water balance in the network is a key element in assessing the efficiency of the water supply in terms of consumption and water loss, so as to make a water balance in the water supply system, the following parameters should be taken into accountant:

- volume of water from the intakes,
- volume of water from the intakes used for own treatment,
- volume of treated water,
- volume of treated water used in the treatment station,
- volume of water supplied into the network,
- volume of water supplied into the network for own needs of water network,
- volume of water invoiced and supplied to consumers.

The main indicators used to characterize the consumption and water loss in water supply are (Lambert & Hirner, 2000; Lambert et al., 1999):

- Non-Revenue Water Benchmark,
- Unavoidable Annual Real Losses,
- Infrastructure Leakage Index,
- Real Loss Benchmark.

NRWB indicator is calculated according to the equation:

$$NRWB = (V_{sp} - V_{sw})/V_{sp} \cdot 100, \qquad (2)$$

where:

$NRWB$	–	Non-Revenue Water Benchmark [%],
V_{sw}	–	volume of sold water [m^3/M·d],
V_{sp}	–	volume of water supplied into the network [m^3/M·d].

Unavoidable Annual Real Losses (UARL) is the annual volume loss, which is considered to be inevitable and economically viable. This means that the removal of small leaks do not cause significant water losses and damages in the vicinity of the water supply and greatly exceeds the material damage caused by these leaks. The indicator is determined from the relation:

$$UARL = [18 \cdot (M+R) + 25 \cdot PW + 0.8 \cdot L_{PW}] \cdot 0.365 \cdot p, \qquad (3)$$

where:

$UARL$	–	Unavoidable Annual Real Losses, [m^3/year],
M	–	the length of the main network, [km],
R	–	the length of the distribution network, [km],
PW	–	water supply connections length, [km],
L_{PW}	–	number of water connections, [-],
p	–	the average amount of pressure in the present measurement zone, [mH_2O],
0.365	–	conversion factor for a year and m^3.

Infrastructure Leakage Index (ILI) is the ratio of the annual volume ratio of losses to UARL, which is described by the relationship:

$$ILI = V_{loss}/UARL, \qquad (4)$$

where:

ILI	–	Infrastructure Leakage Index, [-],
V_{loss}	–	annual volume of water unsold, [m^3/year].

There are two versions of Real Loss Benchmark (RLB) indicator:

- when the number of connections per kilometer water pipeline water supply system (M+R) is less than 20, calculated using the equation:

$$RLB_1 = V_{loss}/(M+R)\cdot 365, \quad (5)$$

where:

RLB_1	–	Real Loss Benchmark, [m^3/km·d],
V_{loss}	–	annual volume of water unsold, [m^3/year],
M	–	the length of the main network, [km],
R	–	the length of the distribution network, [km].

This indicator enables the assessment of the technical condition of the water supply system.

- If the number of connections per kilometer of water pipe network is at least 20, the RLB is obtained through relationship:

$$RLB_2 = V_{loss}\cdot 1000/L_{pw}\cdot 365, \quad (6)$$

where:

RLB_2	–	Real Loss Benchmark, [dm^3/d·water connections],
L_{pw}	–	number of water connections, [m^3/year].

For calculation of individual indicators of the water consumption and losses the following unit indicators are used:

- individual volume of water supplied into the network,
- unit volume of total sold water,
- unit volume of water sold to households,
- unit volume of water loss,
- unit volume of water used for own needs,
- unit volume of nonprofit water,
- hydraulic loading rate per unit of water supply network,
- water loss rate per unit for the entire length of the line.

An important factor that affects the amount of water loss is the age and the material from which pipes are made.

Currently operated water network are made in approx. 40% of the steel and grey iron. It is characterized by old age, significant technological limitations, high vulnerability to corrosion and cracks, possible defects in material and poor quality of workmanship of pipes in the seventies and eighties of the twentieth century.

The rest of the pipe is made of PVC and PE. Permanent changes in the level of water consumption, which have been observed in recent years may be due to the marketisation of water prices and the introduction of individual metering of water consumption. In the spring and summer are also common sporadic attempts to steal water from the hydrants. Water from them is used for irrigation of crops or construction work.

Detailed age of examined pipes is difficult to determine because of the non-updated documents. More than half of the length of the water supply network have more than 40 years, corrosion of materials in pipes can cause significant loss of water when the pipes are in natural soils that shows corrosion properties

3. Results

After performing the analysis, the following results were obtained:

- the average value of the failure rate for distribution pipe in the examined ten-year period is 0.25 failures/km/year, and is lower than the standard recommended criterion (0.5 failures/km/year),
- in the case of water supply connections, the average value of this indicator is 0.3 failures/km/year, and is much lower than the standard criterion of 1.0 failure/km/year,
- only in case of mains the average value is 0.8 failures/km/year which significantly exceeds the criterion value of 0.3 failures/km/year,
- in case of failure rates a downward evolution trend is observed,
- the percentage of water loss in the amount of water introduced into the water supply system in the examined years ranged from 12 to 18%,
- the rate of specific water consumption by households is 110 dm^3/M/d,
- taking into account the number of water connections, the real loss benchmark has reached values in the range of 200-420 dm^3/d/water connections, in recent years of observation this indicator has decreased,
- unavoidable losses increased by 50% as a result of the significant development of the city and the water supply network and the construction of water supply connections, from the value of 515 thousand of m^3 to 800 thousand of m^3,
- the percentage of the volume of non-profit water remained relatively constant in the range of 24-28%,
- the value of the unit index of hydraulic loads in the studied period decreased from 52 to 38 m^3/d/km,
- the values of the ILI index were within the range 2.2-3.3, which, according to the World Bank Institute's Banding System ranking, classifies the condition of the water supply network as good and very good. However, according to the IWA category, the condition of the water supply network of the city of is classified as poor. It should be noted that the resulting value of the ILI indicates the appropriate state of the water supply system, which contradicts the unsold water volume. This is due to a substantial length of the network in relation to sales volume and a high rate of UARL. This is due to the fact that the ILI indicator is referenced to the water supply network parameters (length, pressure) and the obtained results are good, or very good, even though the unsold volume water is higher than the losses which is considered as economically viable - 10%.
- volumes of water used for specific purposes per one consumer represent the following operational situation of the water supply network. The smallest values were recorded for unit amounts of losses. They ranged from 25-35 dm^3/inh/d. Taking into account the volumes of water used by one inhabitant in a household, they were about five times greater and ranged between 100-130 dm^3/inh/d.
- in the considered period of time, an initial slight increase in actual unit losses can be observed, followed by an almost two-fold decrease to the value of 200 dm^3/km/d. The reason for such a large difference may be the improvement of the technical condition of the

pipelines, and thus the reduction of water loss as a result of leaks.

4. Conclusions

It can be concluded that all unit volume indicators relating to water losses show a downward trend in the considered period.

There is a clear decrease in the indicator for the considered water supply system, which proves the effectiveness of the adopted strategy of reducing leakages from the water supply system.

Limiting water losses has a very important impact on the assessment of the activities of water supply companies. Currently, enterprises are taking actions aimed at minimizing the level of water losses through the use of modern measuring devices, continuous monitoring of losses, as well as the successive modernization of water supply networks.

Conducting periodic analyses of the operation of the water supply systems, the water loss, the pipes failure, and the water consumption level is an important factor to maintain the water supply service at high level.

References

Alegre H., Baptista J.M., Cabrera E., Cubillo F., Duarte P., Hirner W., Merkel W., Parena R. (2016), Performance Indicators for Water Supply Services, IWA Publishing, 3rd Edition.

American Water Works Association (AWWA). (2011), Water Audits and Loss Control Programs - Manual of Water Supply Practices, M36 (3rd Edition).

Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the Quality of Water Intended for Human Consumption, OJ L 435, 23.12.2020.

Dohnalik P., Jędrzejewski Z. (2004), *Efficient Water Supply System Operation. Reduction of Water Losses*, LEMTECH Consulting: Cracow, Poland.

EN 15975/1. (2011), Security of drinking water supply. Guidelines for risk and crisis management. Part 1 - Crisis management.

EN 15975/2. (2013), Security of drinking water supply. Guidelines for risk and crisis management. Part 2 - Risk management.

Hirner W. and Lambert A. (2000), Losses from Water Supply Systems: Standard terminology and recommended performance measures, IWA, London 2000.

Kwietniewski M., Roman M. and Kłos-Trębaczkiewicz H. (1993), *Reliability of Water Supply and Sewage Systems*, Arkady: Warsaw, Poland.

Lambert A.O. (1994), Accounting for Losses – the Bursts and Background Estimates Concepts. *Journal of the Institution of Water and Environmental Management*, **8**, 205-214.

Lambert A.; Hirner, W. Losses from Water Supply Systems: Standard terminology and recommended performance measures. Blue Pages 2000, 10, 320–338.

Lambert A.O., Brown T.G., Takizawa M. and Weimer D. (1999), A review of performance indicators for real losses from water supply systems. *Aqua-Journal of Water Services Research and Technology*, **48**, 227-237.

Mays W.L. (1998), *Reliability Analysis of Water Distribution Systems*, American Society of Civil Engineers: New York, NY, USA.

Młyński D., Bergel T., Młyńska A. and Kudlik K. (2021), A study of the water supply system failure in terms of the seasonality: Analysis by statistical approaches. *Journal of Water Supply: Research and Technology-Aqua*, 70, 289-302.

Ociepa E., Mrowiec, M. and Deska, I. (2019), Analysis of Water Losses and Assessment of Initiatives Aimed at Their Reduction in Selected Water Supply Systems. *Water*, 11, 1037

Parka A., Kuliczkowska E., Kuliczkowski A. and Zwierzchowska A. (2019), Selection of pressure linings used for trenchless renovation of water pipelines. *Tunnelling and Underground Space Technology*, **98**, 103218.

Pietrucha-Urbanik K. (2012), Multidimensional comparative analysis of water infrastructures differentiation. In Proceedings of the Conference on Environmental Engineering IV, Lublin, Poland, 3-5 September 2012, 29-34.

Pietrucha-Urbanik K., Tchórzewska-Cieślak B. and Eid, M. (2021), A Case Study in View of Developing Predictive Models for Water Supply System Management, *Energies*, **14**, 3305.

Pietrucha-Urbanik K., Tchórzewska-Cieślak B. and Eid M. (2020), Water Network-Failure Data Assessment. *Energies*, **13**, 2990.

Rak J.R. and Pietrucha-Urbanik K. (2019), An Approach to Determine Risk Indices for Drinking Water–Study Investigation. *Sustainability*, **11**, 3189.

Rak J.R., Tchórzewska-Cieślak B. and Pietrucha-Urbanik K. (2019), A Hazard Assessment Method for Waterworks Systems Operating in Self-Government Units. *International Journal of Environmental Research and Public Health*, **16**, 767.

Rak J.R. and Tunia A. (2012), Analysis and the assessment of losses of water in the water supply system of Rzeszow. *Instal*, **5**, 42-45.

Tchórzewska-Cieślak B., Pietrucha-Urbanik K., Urbanik M. and Rak J.R. (2018), Approaches for Safety Analysis of Gas-Pipeline Functionality in Terms of Failure Occurrence: A Case Study. *Energies*, **11**, 1589.

Urbanik M., Tchórzewska-Cieślak B. and Pietrucha-Urbanik, K. (2019), Analysis of the Safety of Functioning Gas

Pipelines in Terms of the Occurrence of Failures. *Energies*, **12**, 3228.

World Health Organization. (2011), Guidelines for Drinking-Water Quality, 4th ed., World Health Organization, Geneva, Switzerland.