PRACE NAUKOWE Akademii im. Jana Długosza w Częstochowie
Technika, Informatyka, Inżynieria Bezpieczeństwa 2018, t. VI, s. 171–184

http://dx.doi.org/10.16926/tiib.2018.06.13

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ANALYSIS OF FAILURE OF THE WATER NETWORK FOR A SMALL COMMUNITIES IN THE YEARS 2007–2012

Abstract. Water losses and failure of a water supply network is one of the main problems of each Municipal Water District not only in Poland but in the whole world. Water losses, have not only economic consequences, but also ecological. The analysis made and shown in the article concerns of water losses and failure of water supply network operated by The Municipal Water Supply and Sewage Disposal Company in Brzesko in 2007–2012.
Keywords: failure of water supply network, water losses, reliability index of the network.

ANALIZA AWARYJNOŚCI SIECI WODOCIĄGOWEJ MAŁEJ JEDNOSTKI OSADNICZEJ W LATACH 2007–2012

Streszczenie. Straty wody oraz awaryjność sieci wodociągowej należą do głównych problemów eksploatacyjnych Systemów Zbiorowego Zaopatrzenia w Wodę dla każdego przedsiębiorstwa nie tylko w Polsce, ale i w innych krajach świata. W pracy dokonano analizy strat wody oraz awaryjności sieci wodociągowej eksploatowanej przez Rejonowe Przedsiębiorstwo Wodociągów i Kanalizacji (RPWiK) w Brzesku na przestrzeni lat 2007–2012.
Słowa kluczowe: awaryjność sieci wodociągowej, straty wody, wskaźniki niezawodności sieci.

Introduction

Every management unit of water supply network is obligated not only to provide their customers required amount of potable water any time of the day and with proper pressure but also to do it at the best price. The units are able to fulfill the requirements through proper management of the network.The main problems which interfere with proper work of the water supply network and which are faced by all water companies are water losses and failures of the network. Both these problems are important not only for economic and sanitary reasons but environmental also. In reference to cost, they might not be high but noticeable for the single customers. It is also important that water losses contributes to increasing water deficit and infiltration of water through cracks can be a cause of building disasters.

The water losses reduction would be resulting in increased profits for the exploiting company of the network, which is caused, for example, by the reduced costs of water treatment process or lower consumption of electricity used for pumping water [1, 3, 6, 10].

Characteristic of water supply system of considered area

Municipal Water Supply and Sewage Disposal Company provides potable water for three contiguous communities located in southern Poland, in Lesser Poland Voivodeship i.e.Brzesko, Dębno and Wojnicz. The population of the considered area is about 63 thousands citizens [2, 10]. The area is supplied from single Surface water intake located on Dunajec River in Isep Village. Collected water is treated in Water Treatment Plant in Łukanowice and its productivity is 11 200 cubic metres per day. In 2012, the length of the water supply network was 400 km, and potable water was delivered to 37 800 customers. Sales of water covers a total of 9 379 collection points for water in the city Brzesko 1 728, and for the community Brzesko 3 046 2 618 municipalities Debno, municipalities Wojnicz 1987 [10, 13].

Due to the topography there was a need to built pumping station and 22 hydrophore stations. Thanks to that, water can be delivered to customers which are located in the highest places. Moreover water is also accumulated in four water tanks located in Okocim, Jasień, ŁysaGóra and Jadowniki which support the work of the water supply system due to irregular water demand throughout the day [6, 13].

Data from Central Statistical Office of Poland allowed to characterize the structure and value of water consumption in 2007-2012 of the biggest recipient of potable water – city of Brzesko. Total consumption in each of considered year is shown in table 1 and figure 1. The highest value of water consumption was in 2007, and the lowest in 2012 (about 13 % lower).Considering the structure of water consumption, 50,2% of produced water was sold for households, 27,6% for industry, 22 energetics, and 0,2% for other purposes [6, 10, 13].

Table 1. Water consumption level in 2007–2012 in Brzesko

YEAR	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
CONSUMPTION LEVEL $[m^3]$	1072178	983481	948856	1000602	947000	954900

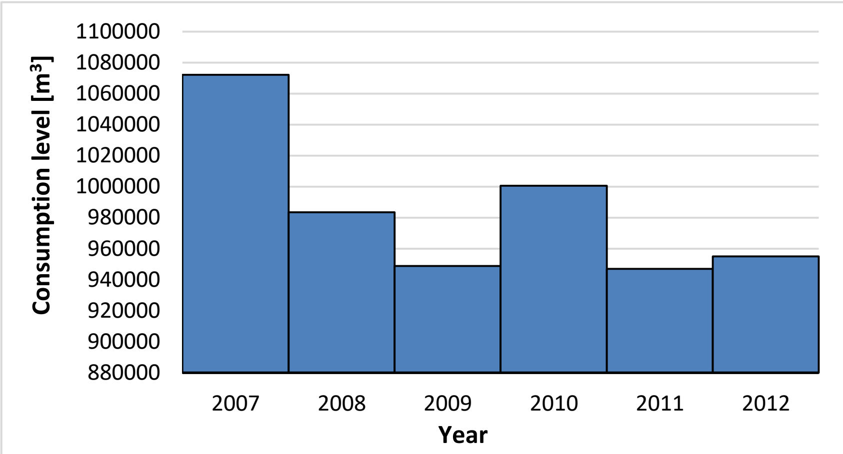

Fig. 1. Water consumption level in 2007–2012 in Brzesko

Data and methods

The indicators recommended by IWA for international comparisons

To evaluate the level of water losses in water supply networks, should designate values of indicators based on annual water balance of the Company.For the analysis the indicators recomended by The Water Association were used. Their values were determined on the basis of such data as (table 2 and table 3) [11, 12]:

- amount of water collected from the intake V_{UJ},
- amount of water crammed into the water supply network V_{DS},
- amount of water used by the Company V_{TS} ,
- amount of sold water (invoiced)V_{SP},
- lenght of the water supply network L_{M+R},
- length of the water supply network including the lenght of water supply linesL_{M+R+PW},
- number of water service lines per kilometer of water supply network M+R,

– number of the water service lines L_{PW},
– lenght of the water service lines PW,
– average pressure in the water supply network (operating pressure)p.

Table 2. Summary balance of water production by the Company in the years 2007–2012

YEAR	$V_{DS}\left[\frac{m^3}{year}\right]$	$V_{DS}\left[\frac{m^3}{year}\right]$	$V_{TS}\left[\frac{m^3}{year}\right]$	$V_{SP}\left[\frac{m^3}{year}\right]$
2007	2 875 700	2 834 300	41 400	1 884 600
2008	2 710 800	2 671 700	39 100	1 818 000
2009	2 844 000	2 766 000	78 000	1 782 200
2010	2 882 200	2 814 700	67 500	1 880 800
2011	2 747 500	2 693 100	54 400	1 818 900
2012	2 954 500	2 893 800	60 700	1 884 700

Table 3. Data for the calculation 2007–2012

YEAR	**M+R** $\left[\frac{piece}{km}\right]$	L_{M+R} $[km]$	L_{PW} $[piece]$	**PW** $[km]$	$p\left[\begin{matrix}water\\column\\meter\end{matrix}\right]$
2007	24	388,9	9379	303,5	45
2008	24	400,2	9691	3150	45
2009	25	403,3	9939	323,4	45
2010	25	410,5	10131	329,6	45
2011	24	429,9	10379	337,7	45
2012	24	452,5	10662	346,9	45

Based on data collected in table 2 one and equation 1 it was possible to determine the value of water losses (V_{STR}) for each of considered year. The value is calculated as a difference between amount of water collected from the intake, water used by the Company and sold water (invoiced). The level of water losses. Water losses in the years 2007-2012 are showing the range of 32 to 36% of the volume of water sold. The Results of calculation was presented in table 4 and on figure 2 figure 2 presents a comparison of sold water and water losses [3, 4].

$$V_{STR} = V_{UJ} - V_{TS} - V_{Sp} \quad (1)$$

Table 4. Value of water losses in 2007–2012 in Brzesko

YEAR	$V_{STR}\left[\frac{m^3}{year}\right]$
2007	949 700
2008	853 700
2009	983 800
2010	933 900
2011	874 200
2012	1 009 100

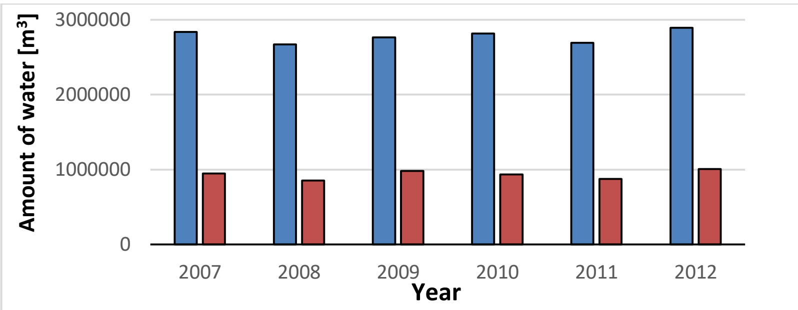

Fig. 2. Comparison of the amount of water sold and water losses in Brzesko in 2007-2012

Percentage indicator of water losses *WSW* – determines the amount of water losses relative to the volume of water crammed into the network [11, 12]

$$WSW = \frac{V_{STR}}{V_{DS}} \cdot 100\% \qquad (2)$$

where:

$WSW -$ percentage indicator of water losses[%],

$V_{STR} -$ value of water losses $\left[\frac{m^3}{year}\right]$

$V_{DS} -$ amount of water crammed into the water supply network $\left[\frac{m^3}{year}\right]$,

$LM -$ number of residents $[Mk]$.

Real Loss Basic*RLB* - there are two versions of this indicator. Before choosing the right one, should determine the daily amount of actual water losses using water balance and requires knowledge of the number of water service lines. The Equation of formula 3 is used, if the number of connections per kilometer network is less than 20, while the tracer of formula 4 is greater than or equal to 20 [11, 12].

The indicator *RLB_1* – determines the volume of water is wasted for every kilometer network, including the length of the water service lines.
The indicator *RLB_2* – determines the volume of water is wasted for every water service line.

$$RLB_1 = \frac{V_{STR}}{(M+R)\cdot 365} \quad (3)$$

$$RLB_2 = \frac{V_{STR}}{L_{pw}\cdot 365} \quad (4)$$

where:

$RLB_1 -$ Real Loss Basic$\left[\frac{m^3}{d\cdot km}\right]$,

$RLB_2 -$ Real Loss Basic$\left[\frac{dm^3}{d\cdot piece}\right]$,

$V_{STR} -$ value of water losses $\left[\frac{m^3}{year}\right]$,

$M + R -$ number of water service lines per kilometer of water supply network $\left[\frac{piece}{km}\right]$.

$L_{pw} -$ number of water service lines [piece].

Non-Revenue Water Basic*$NRWB$* – determines how much of the water crammed into the network does not bring income [10, 11, 12]

$$NRWB = \frac{V_{DS}-V_{SP}}{V_{DS}} \cdot 100\% \quad (5)$$

where:
$NRWB -$ Non-Revenue Water Basic [%],
$V_{SP} -$ amount of sold water (invoiced) $\left[\frac{m^3}{year}\right]$.

Unavoidable Annual Real Losses UARL -The indicator determines the level of inevitable water losses. These losses can be difficult to identify, or the cost of repairing their causes too large. Determination of the value of this indicator can be very difficult, but research conducted by the IWA, on a large number of water supply networks, have given positive results. To determine the value of the indicator is essential knowledge [5, 7, 9]:
- the inevitable leaks in the lines of main and distribution network,
- the inevitable leaks at water service lines to the border of the property,
- the inevitable leaks at water lines from the border of the property,

$$UARL = [18 \cdot L_{M+R} + 25 \cdot PW + 0{,}8 \cdot L_{PW}] \cdot 365 \cdot p \qquad (6)$$

where:

$UARL -$ unavoidable annual real losses $\left[\frac{m^3}{year}\right]$,

$L_{M+R} -$ lenght of the water supply network $[km]$,

$PW -$ lenght of the water service lines $[km]$,

$p -$ average pressure in the water supply network $[water\ column\ meter]$,

$L_{pw} -$ number of water service lines.

Infrastructure Leakage IndexILI - index recommended by IWA to set main goals on the reduction of water losses. It determines how many times the actual losses are greater than the losses inevitable. It also allows to make an indirect assessment of the technical condition of the water supply network. Criteria for evaluation of the ILI index developed by the IWA, WBI Banding System and AWWA are presented in the table 5 [7, 9].

$$ILI = \frac{V_{STR}}{UARL} \qquad (7)$$

where:

$ILI -$ Infrastructure Leakage Index [-],

$UARL -$ indicator of inevitable water losses $\left[\frac{m^3}{year}\right]$,

$V_{STR} -$ value of water losses $\left[\frac{m^3}{year}\right]$.

Table 5. Categories of Infrastructure Leakage Index [7, 9]

Range and categories of ILI according to IWA	ILI Categories	Range of ILI according to WBI Banding System		Range of ILI according to AWWA
		Developing countries	Developed countries	
$ILI \leq 1{,}5$ very good condition	Very good condition	$ILI \leq 4{,}0$	$ILI \leq 2{,}0$	$ILI \leq 3{,}0$
$1{,}5 < ILI \leq 2{,}0$ good condition				
$2{,}0 < ILI \leq 2{,}5$average condition	Good condition	$4{,}0 < ILI \leq 8{,}0$	$2{,}0 < ILI \leq 4{,}0$	$3{,}0 < ILI \leq 5{,}0$
$2{,}5 < ILI \leq 3{,}0$ Poor condition	Poor condition	$8{,}0 < ILI \leq 16{,}0$	$4{,}0 < ILI \leq 8{,}0$	$5{,}0 < ILI \leq 8{,}0$
$3{,}0 < ILI \leq 3{,}5$ Very poor condition				
$ILI > 3{,}5$Inadmissible condition	Inadmissible condition	$ILI > 16{,}0$	$ILI > 8{,}0$	$ILI > 8{,}0$

Unit indicators of water losses

Determination of unit indicators allowed to obtain a detailed picture of the state of water supply system. In the article four indicators were calculated using data from Table 1. In all cases the reference unit was single day, and also in the first two, also a single network user (Mk) and in the last two, kilometer operated network. The working ratio analysis was performed according to the recommendations of Cancer and Tunia and indicators were used, such as [11, 12]:

– **unit volume of water crammed into the network $q_{wtł}$** – this indicator shows how much crammed into the network, falls on a single customer during one day**.**

$$q_{wtł} = \frac{V_{DS} \cdot 1000}{LM \cdot 365} \quad (8)$$

where:

$q_{wtł}$ – unit volume of water crammed into the network $\left[\frac{dm^3}{Mk \cdot d}\right]$,
V_{DS} –amount of water crammed into the water supply network $\left[\frac{m^3}{year}\right]$,
LM – number of residents $[Mk]$.

– **unit volume of a non-profit water q_{nd}**– allows to determine the volume of a non-profit water falls on each customer per day

$$q_{nd} = \frac{(V_{DS} - V_{SP}) \cdot 1000}{LM \cdot 365} \quad (9)$$

where:

q_{nd} – unit volume of a non-profit water $\left[\frac{dm^3}{Mk \cdot d}\right]$,
V_{SP} –amount of sold water $\left[\frac{m^3}{year}\right]$.

– **unit indicator of hydraulic load of water supply network q_o** – allows to determine the volume of water falls on per kilometer od water supply network per day

$$q_o = \frac{V_{DS}}{L_{M+R} \cdot 365} \quad (10)$$

where:

q_o –unit indicator of hydraulic load of water supply network $\left[\frac{dm^3}{km \cdot d}\right]$,
L_{M+R} –length of the water supply network $[km]$.

– **unit indicator of water loss for the entire length of the water supply networkq_{strL}** - allows to determine the volume of water lost per kilometer network per day.

$$q_{strL} = \frac{V'_{STR}}{L_{M+R+PW} \cdot 365} \qquad (11)$$

where:

q_{strL} – unit indicator of hydraulic load of water supply network $\left[\frac{dm^3}{km \cdot d}\right]$,

V'_{STR} – actual water losses $\left[\frac{m^3}{year}\right]$; $V'_{STR} = V_{STR} - UARL,$

L_{M+R+PW} – length of the water supply network including the lenght of water supply lines$[km]$.

Calculation results

The results of the calculations for indicators recommended by IWA are presented in table 6 and the figures 3–8, and for unit indicators of water loss, in Table 7 and figures 9–12.

Table 6. Calculation results of the indicators recommended by IWA

YEAR	WSW [%]	NRWB [%]	RLB_1 $\left[\frac{m^3}{d \cdot km}\right]$	RLB_2 $\left[\frac{dm^3}{d \cdot piece}\right]$	UARL $\left[\frac{m^3}{year}\right]$	ILI [−]
2007	34	33,5	6,7	277,4	362843,03	2,6
2008	32	32	5,8	241,3	375005,75	2,3
2009	36	35,6	6,7	271,2	382630,23	2,6
2010	33	33,2	6,2	252,6	389844,09	2,4
2011	32	32,5	5,6	230,8	402,148,06	2,2
2012	35	34,9	6,1	259,3	416326,12	2,4

Table 7. Calculation results of the Unit indicators of water losses

YEAR	$q_{wtł}\left[\frac{dm^3}{Mk \cdot d}\right]$	$q_{nd}\left[\frac{dm^3}{Mk \cdot d}\right]$	$q_o\left[\frac{dm^3}{km \cdot d}\right]$	$q_{strL}\left[\frac{dm^3}{km \cdot d}\right]$
2007	142,3	47,7	19,97	3,76
2008	132,9	42,5	18,29	3,27
2009	136,7	48,6	18,79	371
2010	136,3	45,2	18,79	3,46
2011	130,1	42,2	17,16	3,12
2012	139,7	48,7	17,52	3,46

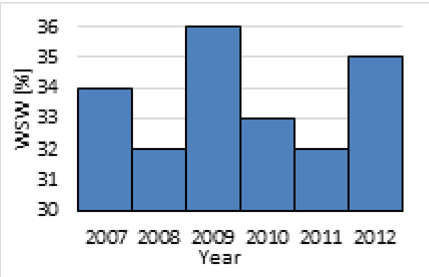

Fig. 3. Graphical representation of the results of calculations for the WSW indicator of considered water supply network in 2007–2012

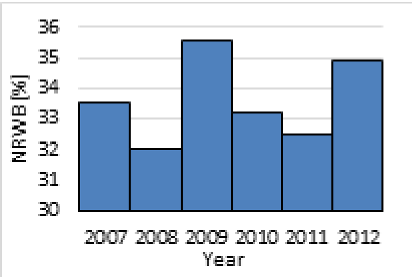

Fig. 4. Graphical representation of the results of calculations for the NRWB indicator of considered water supply network in2007–2012

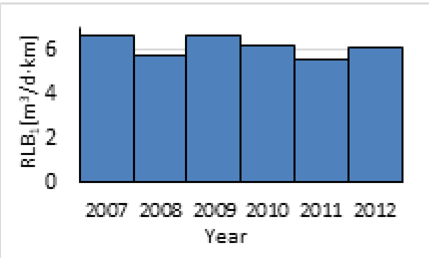

Fig. 5. Graphical representation of the results of calculations for the RLB_1 indicator of considered water supply network in 2007–2012

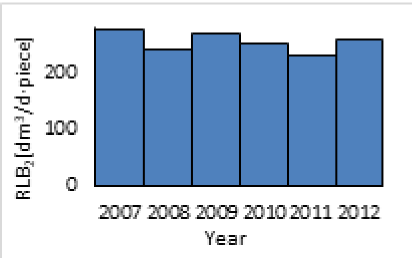

Fig. 6. Graphical representation of the results of calculations for the RLB_2 indicator of considered water supply network in 2007–2012

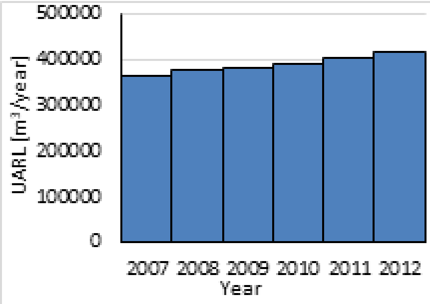

Fig. 7. Graphical representation of the results of calculations for the UARL indicator of considered water supply network in 2007–2012

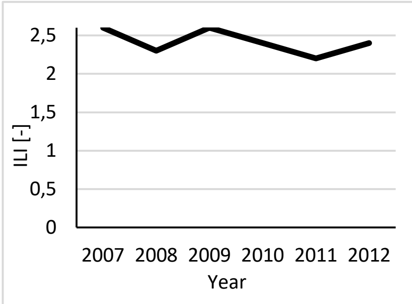

Fig. 8. Graphical representation of thresults of calculations for the ILI indicator of considered water supply network in 2007–2012

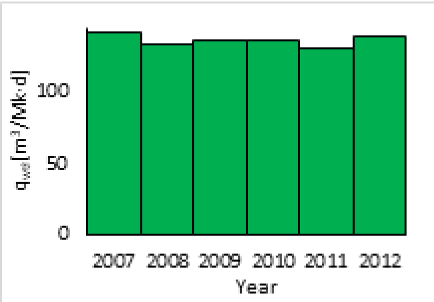

Fig. 9. Graphical representation of the results of calculations for the unit volume of water crammed into the in 2007–2012

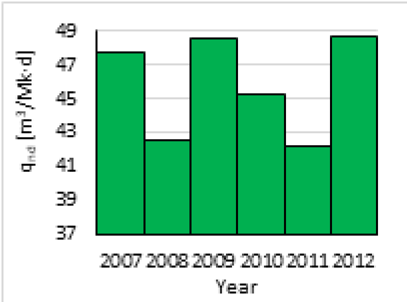

Fig. 10. Graphical representation of the results of calculations for the unit volume of a non-profit water of considered water supply network in 2007–2012

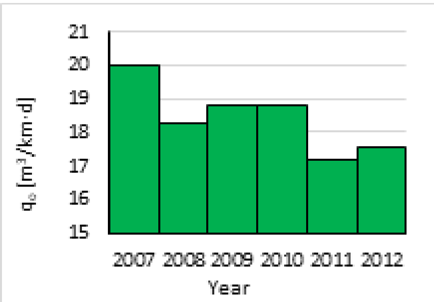

Fig. 11. Graphical representation of the results of calculations for the unit indicator of hydraulic load of water supply network in 2007–2012

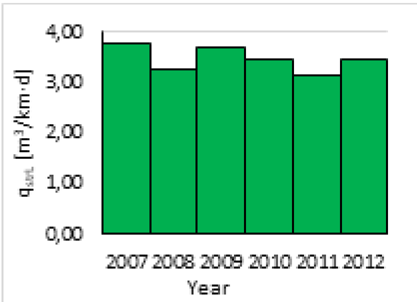

Fig. 12. Graphical representation of the results of calculations for the unit indicator of water loss for the entire length of the water supply network in 2007–2012

Conclusions

Analyzing the changes of the WSW indicator, it's noticeable that in the analyzed period of time, it was not isolated the dominant trend. The indicator values first are rising, and then decrease. The highest value was achieved it in 2009, and the lowest in 2008. The average value is 34%. Changes in the value of WSW index was shown in figure 3.

Due to the fact that the number of water supply service lines per 1 km of the network is equal at least 20, it was justified to perform the calculation using the formula 4, however, for illustrative purposes, this ratio also was determined using the formula 3. Values of the RLB_1 indicator during considered period, was in the range of from 5.6$\frac{m^3}{d \cdot km}$to 6.7$\frac{m^3}{d \cdot km}$ (table 6), and in this case there is also no clear trend changes (figure 5). The highest value, the indicator reached 2007 and 2009, and the lowest in 2011, the average value was 6.1$\frac{m^3}{d \cdot km}$. The values of the Real Loss Basic indicator RLB2 (figure 6), allowed to draw a conclusion that, in terms of one water service line, during considered period, the losses do not changed in a significant way. The difference between the lowest value (230.8 $\frac{dm^3}{d \cdot piece}$ in 2007) and the highest (277.4 $\frac{dm^3}{d \cdot piece}$ in 2011) reached 17%. The values of the indicators point to a good technical condition of the network.

The Non-Revenue Water Basic indicator reaches the most noticeable fluctuations in results (figure 4), even though, the difference between the highest value appearing in 2009, equal to 35.6, the lowest of the year 2009 is just 3.6%.For the considered water supply system, the average value of the index is higher than the average obtained for Denmark, Hungary, France and Finland, while lower for Norway and comparable with Italy, Portugal and the United States [5, 8].

Considering the results of the UARL indicator (figure 7) it clearly can be stated that there is a growing trend. In 2012, the level of inevitable losses increased by 14% compared to 2007. This is mainly due to the still ingrowing length of the network, and thus, the length and the number of water supply service lines. After determining the value of the inevitable losses, it is possible to designate the so-called actual water losses, or loss Vstr,depreciate losses inevitable. After including changes, water losses reach 17–20%. In developed countries, this figure reaches 10% [11]

The average value of ILI indicator (figure 8) for considered water supply network was 2.4, in turn, the values that occurred most frequently are 2.6 and 2,4.Analyzing the values obtained by these two duplicate values, according the IWA criteria IWA, the water supply networks condition is poor (value 2.6) or medium (value 2.4). According to the AWWA criteria, in both cases, the condition can be considered as very good. On the other hand, the criteria of WBI Banding System, on the assumption that Poland is a developed country, in both cases, the network status can be assessed as good, while when we define it as a developing country – very good. For example, the average value of the ILI indicator in South Africa is 4.97, the United States and Canada – 4.27, 2,44 in the UK and Australia 2,3 thus the average value obtained for Brzesko, it ranks high [9].

The unit indicator of water loss for the entire length of the water supply network in considered period of timed remained on the same level, which is a positive phenomenon especially in view of the slowly expansion of water supply network. It is necessary to introduce national standards in this field.

The analysis has provided important information on the state of the water supply network, but in order to assess the direction of development in this subject, should use a longer period of time. At 6 years of research, there could not be seen a trend in the received values.

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