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Water Distribution Subsystem: system failure analysis on view of Critical Infrastructure (CI) resilience and preparedness enhancement and management

Keywords

data collection, water pipe, failure, critical infrastructure

Abstract

The proper function of Water Distribution Subsystem (WDS) and its reliability has been a subject of many scientific researches for over 40 years. Important role in water network operation is water failures monitoring and failure analyse relating to its failure frequency index. The main problem of this kind of analyse is lack of data about failure (pipe diameter, pipe length, information on what street occurred the failure, the cause of failure). In this paper authors focus on analysis of water failure pipes for WDS in Podkarpackie Region. The statistical treatment has been made for real, operational data. Failure analysis and statistic treatment was carried out for pipes due to its function: main pipes, distribution pipes and water connections and according to pipe material. The article indicates the main cause of water pipe failure during the design, construction and operation stage, and also functioning dependence on other critical infrastructures. In addition, selected incidental events recorded in the Polish WDS was presented.

1. Introduction

For several years in Poland great importance is attached to critical infrastructures and their security. Polish legislation aimed at the protection of critical infrastructure is, primarily, the Act of 26 April 2007 on Crisis Management (Journal of Laws of 2007, No. 89, item 590 with subsequent amendments) [29].

The definition of a critical infrastructure (CI) has been clearly laid down in the act mentioned above [29] on crisis management. CIs are understood as systems with mutually bound functional objects, contained therein. They are of key importance for the security of the state and its citizens, as well as serving to ensure efficient functioning of public administration authorities, institutions and enterprises [1], [24], [29].

According to this provision, critical infrastructures include: energy, fuel and energy resources supply systems, communication systems, tele-information network systems, financial systems, food supply systems, water supply systems, health protection systems, transportation systems, rescue systems, systems ensuring the continuity of public administration activities, systems of production, storing and use of chemical and radioactive substances, including pipelines for dangerous substances [24], [29]. The Government Centre for Security (GCFS) defines which structures can potentially be classified as CIs, in collaboration with the relevant ministers and central authorities that are operating the identified infrastructures. Within the framework of the GCFS activities, the National Critical Infrastructure Protection Programme (NCIPP) [23] aims at identifying the installations, facilities and services corresponding to the critical national infrastructures in accordance with Art. 5b, paragraph 7, point 1 of the Act on crisis management [29]. The programme provides a framework in which public administration in collaboration with the CIs owners and operators should ensure the continuity of the CIs service supply [23]. In Poland, for the protection of critical infrastructure, the GCFS

performs the tasks specified in Art. 11 paragraph 2 point 11 of the Act on crisis management and its implementing acts [1], [23]-[24], [29].
These tasks include, among others [1], [23]-[24], [29]:

- building partnerships between all the interested parties,
- building, maintaining and developing the exchange of information between the participants of the programme,
- developing and implementing risk assessment methodology for assessing CIs services disruption,
- performing risk assessments of the occurrence and likelihood of crisis situations may result in by CIs services disruption,
- developing, disseminating and implementing guidelines, recommendations and procedures for crisis management,
- developing support mechanisms to enhance CIs preparedness,
- supporting close cooperation between private sectors and public administrations at all levels (when it is justified), in order to maintain the effectiveness of the programme,
- disseminating the information concerning CIs protection and facilitating the exchange between different stakeholders,
- initiating and supporting tasks related to CI protection, performing scientific, technical and societal research corresponding activities,
- promoting educational programmes and activities aimed at raising awareness in the area of CIs protection,
- performing trainings in the field of CIs protection and crises management,
- evaluating systematically and periodically the effectiveness of the CIP national programme.

Collective water supply systems (CWSS) is a CI. The CWSS resilience and preparedness are enhanced when the system operator applies the safety requirements given in the legislation and standards [2]-[3], [21]-[22], [30]-[31]. In Poland legal regulations for water distribution subsystem (WDS) are, primarily: the Act of collective water supply and sewage disposal [30] and the Regulations of the Minister of Health on the quality of water for human consumption [21]-[22]. With regard to these acts water is safe for human health if it is free from pathogenic microorganisms and parasites and any other substances in quantities hazardous to Man's health and has no aggressive corrosive properties [21]-[22]. For CWSS as for all other CIs, it is fundamental to carry out the following activities: surveillance, failures detection and monitoring, systematic and automatic failure data collection, treatment and storage in structured databases. Failure data collection, treatment, storage and retrieve are considered as strategic underlying activities within the framework of enhancing the CWSS preparedness and resilience. They are equally of high importance for effective crises managing [1], [24], [29].
CWSS failure data should include not only failure mechanisms, modes, causes and their criticality but also the major threats to which the failure mechanisms are the most sensitive such as: flooding, quacks, very cold temperatures, chemical-biological pathologic agents [7], [9], [10], [18]-[19].
The main aim of the study is to present the analysis of failures for a water distribution subsystem, as a part of a critical infrastructure. The analysis of the causes of failures in the water network and their characteristics were presented. The functioning of WDS was presented due to other critical infrastructures. The paper presents examples of incidental events that occur in Poland.

2. Specific character of the water distribution subsystem

The collective water supply system is created by the systems forming an integral whole and having different functions [12]-[14], [17]. The CWSS can schematically be described as in *Figure 1*.

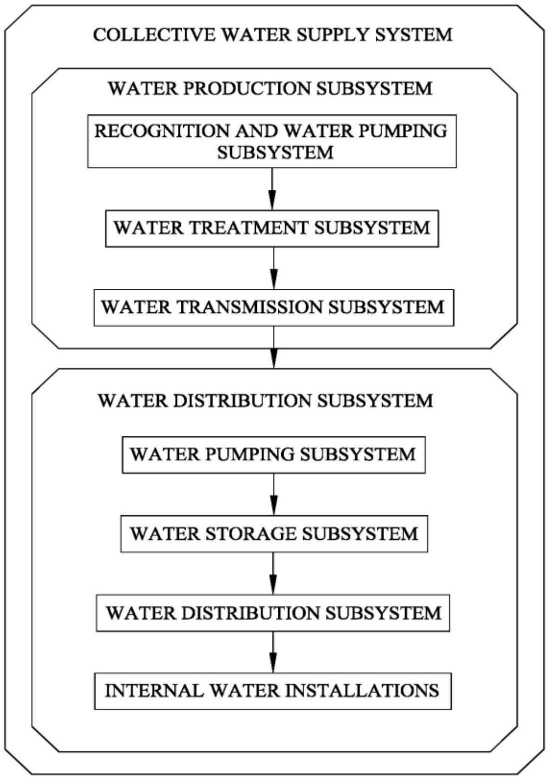

Figure 1. Block diagram of the collective water supply system

Water distribution subsystem (WDS) is one of the two main subsystems constituting the water supply CI and has a strategic role in the public water supply. The water distribution subsystem consists of water pipe network (main, distribution and water connections) together with the specific fittings (gate valves, check valves, hydrants, drainage, aeration, flow meters). Some failures can cause the losses of water supply, as well as they can be a reason for a secondary contamination of the water flowing in the pipes, which may be a serious threat to consumers' safety [4], [8], [10]-[12], [14]-[15]. The WDS has the highest failure frequency in a CWSS. The system overall reliability is evidently dependent on the failures occurrence and on the maintenance of the network operational. The reliability of the system measures the system ability to provide consumers with the demanded quantity of water with the required quality [21]-[22]. As far as water pipe network is concerned, the current failure database contains only the final data which do not integrate the primary causes of failures. The collected regional data are partly in a digital form but the rest are in the form of paper data sheets. It is always possible to answer the question about what kind of failure took place, e.g. corrosion, transverse crack, longitudinal crack. But, it is much more difficult to identify the cause of a failure [5].

The best exploitation of a WDS relies on a regular control of water pipe network operating conditions and the quality of its fittings. That include [10], [13]-[14], [26]-[27]:

- the pressure and the rate of flow monitoring,
- water pipe network fittings inspection,
- new water pipe network and connections construction,
- repair of water pipe network and its fittings, as well as eliminating failures causes if possible,
- regular inspection of tanks in water pipe network,
- water pipe network continuous repairs (repairs as a result of daily and periodic inspections):
- pipes renovation,
- inside surface cleaning when it is covered with cement mortar or epoxide mortar,
- flexible lining (insitu form, phoenix),
- pipes reconstruction:
  - long pipes relining,
  - compact pipe (U-liner) (plastic pipes are introduced into pipe being repaired),
- pipes renewal:
  - using the trench method ,
  - using the trenchless method,
  - old pipe is removed,
  - old pipe remains,
- water quality monitoring in water-pipe network and in water-pipe tanks (measurements are made in the selected points of water-pipe network that should be located evenly in the whole WDS, should include characteristic water quality indicators, and their frequency should be precisely determined by legal norm, according to the sanitary service recommendations).

With regard to the specifications of the water pipe network operating modes, failures repair and the corresponding maintenance actions impact strongly on the network reliability and on the quality of the water. On the question what kind of failure mechanisms or modes appeared, we can give answers such as: corrosion, transverse crack, longitudinal crack etc. However, it is much more difficult to identify the cause of failure.

3. Failure data sensitivity to different threats

3.1. Causes of failures in the WDS

The operation of the WDS often involves the probability of the occurrence of various types of undesirable events that may cause losses of water, interruptions in water supply or secondary water pollution in the network. It has been shown in the literature that the failure rate of water pipes is influenced by many factors, e.g.: unstable ground, age of pipes, function of pipes (transit, main, distribution and water connections), water pressure in the network, water flow rate, corrosive soil, groundwater characteristics and soil hydrology as well as the pipes material and the related method of pipes joining. Operational tests also show the impact of the seasons, the environmental conditions and the ground and water temperature on the failure rate [10], [14]-[15], [18], [25]-[26]. Failures in the WDS can be also the consequences of the errors made during: system design, construction and operation [8]-[10], [12], [14], [18], [26]-[27].

In the design stage the basic errors could be the following:

- errors in water-pipe network layout (wrong examination of ground conditions, badly selected route of water pipeline, neglecting the neighboring economic activities of a third party),
- wrong concept of the water-pipe network geometry and structure,
- errors in hydraulic calculations (water-pipes diameter, water-pipes length before intersections, network required pressure and pressure drops),
- wrong concept of the WSS control systems and procedures.

In the construction stage:

- deviations from the design codes and the rules of correct construction, according to valid regulations, regarding the technology of pipes laying, the connection of the individual pipe sections; the protection of pipes going under and through the obstacles, the use of proper anticorrosion protection (passive and active), the use of the recommended pressure test and other procedures.

In the operating stage:
- incorrect operating procedures,
- lack of water pipeline operation monitoring,
- not taking properly into account the emergency water supply capabilities,
- incoherent protecting and warning system for water quality,
- lack of program to classify the network segment requiring the repair,
- lack of program to obtain, process and store the failure data and their causes, consequences and criticalities and lack of failure statistics.

The most often, the failures in the WDS concern:
- pipe body (cracks, tearing off, corrosion pits),
- joints or expansion units (leak in connections),
- fittings, such as: gate, valve, reducer, hydrant, aeration, band, spotter and so on.

Another important problem is the capturing, processing and storing the data of all disturbances in the WDS inline during operation and produce failure statistics. This what we call a Supervisory Control and Data Acquisition (SCADA) systems. The failure data should contain information concerning the date of failure, the kind of failure, the detailed data to identify water-pipe network section, i.e. a kind of water-pipe network (main, distributive, connections to buildings), the kind of the material (steel, grey cast iron, spheroidal iron, plastics), the pipeline geometry and age, the working pressure and flow rate, as well as the data concerning water-pipe network localization, ground conditions, depth of foundation, time of repair and repair time [5], [12].

3.2. Failure in WDS with incidental character

Most water companies are prepared to cope with the consequences of regularly occurring water supply network operation failures. However, some rare sever failures may result in a real crisis. An incidental event in CWSS is defined as a failure event whose occurrence may threaten the lives and the health of water consumers, may cause considerable damage to the water supply company or to the national economy, may disturb the social and political stability or may endanger the governance effectiveness. The probability of such an event may be determined using the probabilistic risk analysis [7]-[8], [16], [26]. Also the occurrence probability may be very low, the societal losses may be unbearable for the society. That is why CWSS are considered as a critical infrastructure (CI) in most of the societies.

3.3. WDS functioning dependence on other CI's

The functioning of WDS depends to large extend on the normal functioning of some other critical infrastructures. There are three groups of threats affecting the functioning of the WDS. The first group is the other underground infrastructures (transmission). These other CIs can be: the telecommunication lines, the power transmission cables, the gas pipelines, the heat pipelines and the sewage systems (sanitary, rain, general). Failures of sewer pipes and their leaks can impact on the deterioration of water quality parameters through surface and groundwater intakes. The extensive failures of electrical and power systems, such as blackout, can cause negative consequences and affect the WDS: pumping stations, network monitoring system and SCADA systems. Therefore, emergency power supply systems are foreseen to provide electrical power when necessary. The second group is streets, road and highways (transportation), including transportation of dangerous substances, e.g. oil derivatives. The failure of such systems often causes irreversible degradations in the environment and affects the quality of groundwater, which in many cities is the major source of water supply. The third group includes the external threats caused by the forces of nature, i.e. flood, drought and landslides that may affect the structure of the water supply network and the corresponding water intakes. Finally, one must also pay attention to cyber-threats created by the telecommunications systems.

4. The example of the WDS failure analysis

4.1. Characteristic of the WDS

The analysis of the WDS failures was made for a town supplied through surface water intakes with a total capacity 77 tys. m3/d situated in the east of Poland, with the following specifications:
- the total length of the water supply network is 890 km,
- the main network of pipes made of cast iron and steel – 50 km,
- the distribution network made of cast iron, steel, PE and PVC – 520 km.
- the water supply connections to the inhabitants are mainly made of galvanized steel, cast iron, PE and PVC – 324 km.

Table 1. The failure data of the water supply network and connections sorted out according to the type of materials and basic statistical characteristics, from 2005 to 2013

Years	**Material**				
	Steel	**Galvanized steel**	**Cast iron**	**PE**	**PCV**
2005	52	37	138	3	11
2006	58	46	154	17	21
2007	60	57	117	10	11
2008	55	34	97	12	18
2009	48	33	102	19	13
2010	62	47	108	24	12
2011	87	46	116	28	18
2012	102	34	110	21	14
2013	106	26	87	23	14
Basic statistical characteristics					
Standard deviation	20,95	9,04	19,44	7,41	3,33
Median	60,00	37,00	110,00	19,00	14,00
Average value	70,00	40,00	114,33	17,44	14,67
Variance	438,89	81,78	378,00	54,91	11,11
Percentile 0,25	55,00	34,00	102,00	12,00	12,00
Percentile 0,55	60,80	40,60	112,40	19,80	14,00
Percentile 0,75	87,00	46,00	117,00	23,00	18,00

Table 2. The failure data of water supply network and connections sorted out according to failure modes and basic statistical characteristics, from 2005 to 2013

Years	**Failure modes**				
	Unsealing	**Fracture**	**Corrosion**	**Crack**	**Mechanical damage**
2005	105	34	96	10	0
2006	107	47	118	24	2
2007	82	28	127	18	0
2008	71	30	102	15	0
2009	75	40	88	12	2
2010	76	32	127	19	1
2011	107	31	145	16	0
2012	95	32	145	11	0
2013	65	37	136	20	0
Basic statistical characteristics					
Standard deviation	15,70	5,58	19,81	4,36	0,83
Median	82,00	32,00	127,00	16,00	0,00
Average value	87,00	34,56	120,44	16,11	0,56
Variance	246,44	31,14	392,25	18,99	0,69
Percentile 0,25	75,00	31,00	102,00	12,00	0,00
Percentile 0,55	87,20	32,80	127,00	16,80	0,00
Percentile 0,75	105,00	37,00	136,00	19,00	1,00
Value range	65-107	28-47	88-145	10-24	0-2

Table 3. Failure rates for water supply network and connections and basic statistical characteristics for failure data from 2005 to 2013

Years	**Type of water pipe**				**Water connections**	
	Main		**Distribution**			
	Number of failures	**λ_M fail./km·y.**	**Number of failures**	**λ_D fail./km·y.**	**Number of failures**	**λ_{WC} fail./km·y.**
2005	54	1,09	108	0,31	83	0,29
2006	45	0,91	136	0,35	117	0,41
2007	51	1,03	114	0,26	90	0,28
2008	29	0,59	106	0,24	83	0,26
2009	38	0,76	114	0,24	65	0,20
2010	39	0,78	114	0,23	102	0,32
2011	52	1,04	113	0,22	134	0,41
2012	55	1,10	109	0,21	119	0,37
2013	36	0,72	111	0,21	111	0,34

Basic statistical characteristics			
Parameter	Main pipes	Distribution pipes	Water connections
Standard deviation	0,18	0,05	0,07
Median	0,91	0,24	0,32
Average value $\lambda_{av.value}$	0,89	0,25	0,32
Minimum value $\lambda_{min.value}$	0,59	0,21	0,2
Maximum value $\lambda_{max.value}$	1,10	0,35	0,41
Variance	0,03	0,002	0,004
Percentile 0,25	0,76	0,22	0,28
Percentile 0,55	0,96	0,24	0,31
Percentile 0,75	1,04	0,26	0,37
Value range of λ_M	0,59-1,10	0,21-0,35	0,20-0,41

4.2. The water distribution subsystem failure frequency

The first step in risk analysis of lack of water supply is to analyse possible undesirable events (failures) which may occur in the subsystem [4], [6], [10], [12]-[13], [18], [20], [26]-[28].

An assessment of water pipes' failures and water supply connections is presented in this paper. It is based on accumulated operational data over 9 years of exploitation of a given water network from 2005 to 2013. The assessment covers data collection, sort out and verification. The water supply network including the connections was sorted out according to type of materials (*Table 1*) and according to failure mode (*Table 2*).

Having collected the failure data and sorted them out, the failure indices of intensity (failure rates) λ, have been estimated for: the main network (λ_M), the distribution network (λ_D) and water supply connections (λ_{WC}). The estimated failure indices were estimated based on the current operating data and according to formula (1) [6], [10], [13]-[14], [18], [20]:

$$\lambda = \frac{n(\Delta t, L)}{L \cdot \Delta t}, \qquad (1)$$

where: λ - unit failure rate, *failure/km·year*
n (Δt) - number of failures in a time interval Δt,
L - length of the pipes, *km*,
Δt - considered time interval, *years*.

5. Examples of incidental events in Poland

In this chapter, we analyse the incidental events recorded in the Polish water supply system database, covering the years 2010-2012. The most frequent incidental events, occurred in the selected provinces of Poland, were the failures of water pipes, the microbiological contamination and the low physico-chemical quality.

In order to determine the basic statistical characteristics of the incidental events, the incidental event duration time was used. *Table 4* shows the list of the incidental events recorded in the years 2010-2012 in the selected Polish provinces. The list was created based on press reports and the official information available on the websites of the Provincial Sanitary – Epidemiological Stations.

Table 4. Some incidental events in Polish selected provinces in 2010-2012

PLACE	EVENT	THE DATE OF COMMENCEMENT	DURATION [h]
Dolnośląskie region			
Lwówek Śląski	Water pipe failure	12.01.2010	16
Kostomłoty	Exceedance of nickel in the water	18.01.2010	6
Źródła	Microbiological contamination of water (coliform bacteria)	19.01.2010	6
Lwówek Śląski	Water pipe failure	27.01.2010	5
Gryfów Śląski	Water pipe failure	07.05.2010	5
Ogorzelec	Exceedance of bacteriological parameters	11.05.2010	6
Lwówek Śląski	Water pipe failure	30.06.2010	16
Ziębice	Microbiological contamination of water (coliform bacteria)	13.08.2010	168
Jemna	Exceedance of bacteriological parameters	13.08.2010	6
Bogdanów	Exceedance of bacteriological parameters	23.08.2010	6
Budziszów	Microbiological contamination of water (coliform bacteria)	23.08.2010	216
Gryfów Śląski	Water pipe failure	30.11.2010	16
Chojnów	Microbiological contamination of water (coliform bacteria)	17.08.2011	6
Białawy Wielkie	Microbiological contamination of water (coliform bacteria)	19.08.2011	6
Laski	Trichloromethane contamination	23.08.2011	6
Gryfów Śląski	Water pipe failure	19.12.2011	5
Kąty Wrocławskie	Water pipe failure	08.02.2012	48
Gryfów Śląski	Water pipe failure	09.02.2012	5
Lubomierz	Water pipe failure	10.02.2012	5
Kąty Wrocławskie	Water pipe failure	13.02.2012	16
Kąty Wrocławskie	Water pipe failure	14.02.2012	5
Kąty Wrocławskie	Water pipe failure	15.02.2012	16
Lubiąż	Water pipe failure	15.02.2012	5
Gryfów Śląski	Water pipe failure	15.02.2012	5
Kąty Wrocławskie	Water pipe failure	24.02.2012	16
Gryfów Śląski	Water pipe failure	24.02.2012	5
Proszówka	Water pipe failure	24.02.2012	5
Kąty Wrocławskie	Water pipe failure	07.03.2012	16
Kąty Wrocławskie	Water Treatment Plant failure	08.03.2012	48
Kąty Wrocławskie	Water pipe failure	26.03.2012	5
Zachodniopomorskie region			
Golczewo	Microbiological contamination of water (coliform bacteria)	25.01.2012	96
Glewice	Microbiological contamination of water (coliform bacteria)	14.01.2012	72
Glewice	Microbiological contamination of water (coliform bacteria)	12.01.2012	168
Czarne Małe i Łysinin	Microbiological contamination of water (coliform bacteria)	04.01.2012	240
Miłowo	Microbiological contamination of water (faecal enterococci)	23.12.2011	72

Suchowo	Microbiological contamination of water (coliform bacteria)	19.12.2011	72
Ciesław	Microbiological contamination of water (faecal enterococci)	16.11.2011	192
Recław	Microbiological contamination of water (faecal enterococci)	16.11.2011	120
Piaski Wielki	Microbiological contamination of water (faecal enterococci)	16.11.2011	120
Krzymów	Microbiological contamination of water (faecal enterococci)	09.11.2011	144
Kaleń	Microbiological contamination of water (faecal enterococci)	04.11.2011	144
Miłowo	Microbiological contamination of water (faecal enterococci)	27.10.2011	264
Wisław	Microbiological contamination of water (faecal enterococci)	27.10.2011	168
Glicko	Microbiological contamination of water (faecal enterococci)	13.10.2011	336
Świętoujść	Microbiological contamination of water (faecal enterococci)	19.10.2011	216
Tetyń	Microbiological contamination of water (faecal enterococci)	14.10.2011	192
Sępolno Wielkie	Microbiological contamination of water (coliform bacteria)	14.10.2011	144
Piasek	Microbiological contamination of water (faecal enterococci)	05.10.2011	72
Kosierzewo	Microbiological contamination of water (coliform bacteria)	07.10.2011	6
Piaski	Microbiological contamination of water (coliform bacteria and faecal enterococci)	20.09.2011	240
Godków Osiedle	Microbiological contamination of water (coliform bacteria)	16.09.2011	120
Przemocze	Microbiological contamination of water (coliform bacteria)	26.08.2011	144
Ognica	Microbiological contamination of water (faecal enterococci)	19.08.2011	120
Chlebowo	Microbiological contamination of water (faecal enterococci)	02.06.2011	192
Łódzkie region			
Mieleszyn	Microbiological contamination	28.05.2010	672
Wieluń	Microbiological contamination	04.08.2010	192
Gałkówek-Kolonia	Microbiological contamination of water (coliform bacteria)	27.08.2010	168
Paprotnia	Microbiological contamination of water (coliform bacteria)	09.11.2010	528
Miedzana Murowana	Physicochemical deterioration of water quality	04.07.2011	6
Olsza	Microbiological contamination of water (coliform bacteria)	08.07.2011	360
Burzenin	Microbiological contamination of water (coliform bacteria)	04.08.2011	480
Wieluń	Microbiological contamination	11.08.2011	216
Lubczyna	Microbiological contamination	08.09.2011	168
Józefów Stary	Microbiological contamination	15.09.2011	216
Dzietrzkowice	Microbiological contamination	22.09.2011	456
Dąbrowice	Microbiological contamination	13.10.2011	216
Strzelna	Microbiological contamination of water (coliform bacteria)	25.11.2011	360
Działoszyn	Microbiological contamination of water (coliform bacteria)	09.02.2012	216

Wielgie	Microbiological contamination	16.03.2012	96
Lubelskie region			
Poniatowa	Trichlorethylene and tetrachloroethene exceeding	13.05.2010	216
Małaszewicze	Microbiological contamination	23.07.2010	168
Aleksandrówka	Microbiological contamination	12.08.2010	216
Koszarsko	Microbiological contamination	13.08.2010	144
Krasnystaw	Microbiological contamination	17.09.2010	144
Błażek	Microbiological contamination	22.09.2010	144
Goraj	Microbiological contamination	29.09.2010	192
Dziekanów	Microbiological contamination	02.06.2011	192
Wypnisze	Microbiological contamination	19.08.2011	168
Rudno	Microbiological contamination	14.09.2011	144
Nielisz	Microbiological contamination	14.09.2011	72
Popielarnia	Microbiological contamination	07.10.2011	96
Podkarpackie region			
Przemyśl centrum	Water pipe failure	09.03.2011	16
Przemyśl ul. Pola	Water pipe failure	05.04.2011	16
Przemyśl os. Rycerskie	Water pipe failure	18.12.2011	16
Rzeszów ul. Podwisłocze	Water pipe failure	31.12.2011	16
Rzeszów ul.Zygmuntowska	Water pipe failure	03.02.2012	16
Rzeszów ul. Sikorskiego/Biała	Water pipe failure	05.02.2012	16
Jarosław	Water pipe failure	14.02.2012	16
Sanok	Microbiological contamination of water (coliform bacteria)	28.02.2012	168
Rzeszów ul. Strzelnicza	Water pipe failure	12.04.2012	16

Table 5. Basic statistical characteristics of the duration of the incidental event in the selected regions, in Poland in 2010-2012

Region	**Number of events**	**Percentile 0,25**	**Percentile 0,55**	**Percentile 0,75**	**Standard deviation**
dolnośląskie	30	5	6	16	47,61
zachodniopomorskie	24	114	144	192	73,93
łódzkie	15	180	216	408	180,39
lubelskie	12	144	168	192	43,97
podkarpackie	9	16	16	16	50,67
overall	90	459	550	824	396,57

Table 6. Classification of incidental events, by type of event in the selected regions in Poland 2010-2012

Region	**Type of events**					
	Failure duration < 24h	**Failure duration > 24h**	**Microbiol. contamin. < 24h**	**Microbiol. contamin. > 24h**	**Physico-chemical contamin. < 24h**	**Physico-chemical contamin. > 24h**
dolnośląskie	19	2	6	2	1	-
zachodniopomorskie	-	-	1	23	-	-
łódzkie	-	-	-	14	1	-
lubelskie	-	-	-	11	-	1
podkarpackie	8	-	-	1	-	-
overall	27	2	7	51	2	1

6. Conclusion

The collective water supply system belongs to critical infrastructure. Therefore, the operation of water companies should be directed at ensuring the safety of CWSS, preparation of emergency response plans and to reduce the effects of a possible occurrence of every undesirable event which may occur in the system. In identify the water network it is necessary to carry out for water pipes failure analysis based on actual, operating data.

The analysis of the failure rates shows that most often failures occur in pipes made of cast iron. The average number of failures in the examined period is 114. Such situation is influenced by the age and the effective operating time of the pipes. The smallest number of failures has occured in pipes made of plastic, with the average number of failures of: 17 for PE pipes and 15 for PVC pipes. The highest failure rate was recorded for the main pipes in 2005, λ_M = 1,09 failure/km·year and the lowest was in 2008, λ_M = 0,59 failure/km·year. In the distribution network the highest failure rate was recorded in 2006, λ_D = 0,35 failure/km·year and the lowest were in 2012 and 2013, λ_D = 0,21 failure/km·year. The highest failure rate in the water connections was recorded in 2006 and 2011, λ_{WC} = 0,41failure/km·year and the lowest was in 2009, λ_{WC} = 0,20 failure/km·year. The presented assessment is the starting point for a more comprehensive water supply system risk assessment in the scope of an overall critical infrastructure resilience and preparedness management.

The analysis of data on incidental events shows that the most common was microbiological contamination lasting longer than 24 hours, which was recorded in Zachodniopomorskie region 23 times. Worth attention are also data showing the high failure rate of water pipes in Dolnośląskie region (a total of 21 failures). The failure rate of water supply network probably occurred as a result of mining coal and other minerals.

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