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Changes of trihalomethanes (THMs) concentration in water distribution system

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ABSTRACT

The article describes the concentration of THMs in drinking water from the selected zone of a water supply system situated in the particular city of the Upper Silesia metropolitan area. The lowest and the highest flows in the selected zone were chosen on the basis of data analysis collected during a 4-year period. Based on the selected lowest and highest water flows during the chosen period, water samples from the water distribution system were collected. In collected samples, the concentrations of the total THMs, chloroform (TCM), bromoform (TBM), dibromochloromethane, and dichlorobromomethane were determined. Samples were collected from the well meter, domestic lines with water main, and water installation inside the buildings (tap water). The aim of the investigation is to study the impact of water flow rate, type of the pipe material, and length of the network on the concentration of THMs in the water supply system.

Keywords: Drinking water; Chloroform (TCM); Bromoform (TBM); Dibromochloromethane (DBCM); Dichlorobromomethane (DCBM); Water flow rate; Pipe material; Network length

1. Introduction

Disinfection is the last step in the water treatment plant for the protection of public health. One of the most commonly used water disinfectants is chlorine. Its commonness is the result of many factors: its low cost, convenience of application, and effectiveness to kill most micro-organisms [1,2]. Unfortunately, natural organic matter (NOM) in water reacts with chlorine to form THMs as disinfection by-products (DBPs). THMs constitute the major category of DBPs [3,4]. Chloroform ($CHCl_3$), bromoform ($CHBr_3$), bromodichloromethane ($CHCl_2Br$), and dibromochloromethane ($CHClBr_2$) are the four compounds belonging to the group of THMs [1–4]. The presence of THMs in chlorinated drinking water and their lifetime exposure on humans have raised a great concern due to its carcinogenicity and recognition as potential risk to human health [1–14]. Several epidemiologic studies have suggested a linkage between THMs exposure and risk of bladder, colon, and rectum cancers [5,13]. Exposure to THMs is also found to be associated with adverse reproductive outcomes [12,13]. The non-cancer effects of THMs are jaundice,

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neurobehavioral effects, subjective central nervous system effect, and enlarged livers but these effects are very unlikely [13]. Due to the hazardous nature of TMPs to the human health, USEPA has established the maximum contaminant level for total trihalomethanes, describes as the sum of the mass concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform, below 80 μg/L in drinking water [15]. According to the Polish regulation, the sum of the mass concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform has to be below 100 μg/L in drinking water [16]. THMs are consumed during drinking, showering, bathing, and swimming through three routes: ingestion, contact with skin, and inhalation [3–10,14,17].

The kinetics of the formation of THMs depends on many factors. The most well known of them are water pH and temperature, contact time, residual chlorine, seasonal fluctuation, NOM concentration, flow rate, and construction and management of the drinking water supply system [1,2,18–30]. In the article, only some selected factors such as water pH and temperature, reaction time, flow rate, and material of pipes will be described.

The THMs increase at high pH as a result of many hydrolysis reactions that have the greatest overall effect on THMs formation. Generally, when pH values are high, more hypochlorite ions are formed, reducing the effectiveness of chlorine disinfection. At higher pH values, more THMs is formed, whereas more HAA is formed when pH values are lower [28]. Also, the rate of formation of THMs generally increases with increasing temperature. Researches [4,6,7,10,22,23,28,29] have demonstrated that the concentration of THMs can increase significantly between the water distribution system and the consumer's tap due to stagnation in warm water pipes. As a result, the use of supply water (consumption and/or showering purposes) after a long period of stagnation in warm water pipes and/or heating in the hot water tanks may significantly increase risks to human health [6,28,29].

Reaction time is the most important factor determining the formation process of THMs under conditions where a disinfectant residual persists. The reaction time depends on the distance between disinfection points and sampling points in a distribution system. The observations from full-scale treatment plants and distribution systems [1,2,4,21,22] have shown the THMs-chloroform ratio to be high in the early stages of the reaction and drops slowly with reaction time. As a result, at locations with the highest water age, the concentration of THMs in chlorinated distribution systems is expected to be highest where the contact time between water and free chlorine is the longest [1,2,4,22].

The small flow rate of water is the consequence of reducing water demand and hence long time of water transportation in the water supply system. Also, the direction of water flow changes in the network because of the deposition of mineral and organic (biofilm) matter on the surface of the pipes [1,2]. Concentrations of THMs at various locations in chlorinated distribution systems exhibit appreciable diurnal variations that match the diurnal variations in residual chlorine and water age [4,22,30]. At times of the day when water demand is low, water stagnation in the system takes place and water age at the sampling location is longer, whereas THMs levels tend to be at a minimum. At other times of the day, when the water demand is high and chlorine residuals are lower, THMs concentrations are correspondingly higher [1,2,4,22,30].

Further investigations [1–4,6–8,10,13,19–23,25,26,28,30] revealed that the formation of THMs in the water supply system is the effect of various factors, which occur in drinking water. The research study was conducted to indicate the impact of water flow rate, type of the pipe material, and length of the network on the concentration of THMs in the selected water supply system.

2. Materials and method

2.1. Materials

The properties of municipal water entering the house from the public water distribution system and occurrence of THMs within the well meter, domestic line, and tap water were investigated for the selected water supply zone located in Southern Poland. The research area is a highly industrial region. The water distribution system is supplied by surface water. The surface water is chlorinated and it is predestined to the formation of THMs in drinking water. In the selected water supply zone, six objects were selected: well meter (Ob1), public school (Ob2), public hospital (Ob3) and social welfare building (Ob4), low-rise building (Ob5), and high-rise building (Ob6). The well meter (Ob1) is the beginning point in the researched water supply zone and it is treated as a reference object. The characteristics of the drinking water supply infrastructure (diameter, length, and material of pipelines) for each object are presented in Table 1.

Water was chlorinated in the water treatment plant located 30 km from well meter, but it was also occasionally chlorinated in the water supply system.

Table 1
Characteristics of drinking water supply infrastructure for selected objects

	From well to domestic line			Domestic line			From domestic line to tap		
Sample points	Length (m)	Diameter nominal (mm)	Type of material	Length (m)	Diameter nominal (mm)	Type of material	Length (m)	Diameter nominal (mm)	Type of material
Ob2	33.0	160-90	PE	5.1	90	Steel	6.3	75-35-25	Steel
Ob3	59.4	125-100	Steel	10.5	100-90	PE	8.9	40-25	PE
Ob4	80.4	160-90-63	PE	4.6	63	PE	7.3	63-40-20	Steel
Ob5	39.2	160-80-63	PE	3.1	63	Steel	4.7	63-40-20	Steel
Ob6	51.0	150-125-90	Steel	4.8	90-65	Steel	22.4	65-40-25	Steel

2.2. Sampling program

Water samples were collected from February 2014 to May 2014 through eight sampling programs at two-week intervals (two in February, two in March, two in April, and two in May) for five buildings and one well meter (11 sample locations). The buildings represented public objects: school, hospital and social welfare building, as well as the private buildings: low-rise building and high-rise building. The selected buildings were located at different distances from the well. Various locations of the buildings and the distance between the domestic line and tap water might have an influence on the concentration of THMs in tap water. At each sampling location, samples were collected at two different times during the day (between 2:00 and 5:00 and between 8:00 and 11:00). Samples were taken by the order of: the lowest and the highest water demands in water supply zone. The time and date of the sampling collection were determined on the basis of a database of hourly flows from 2010 to 2013 in the total number of 11,136 data. Table 2 presents the results of hourly flows analysis from 2010

Table 2
Hourly flows measurement analysis during the period 2010–2014

Day hour (h)	Flow (average) (m^3/h)	Flow (std error)	Flow (−95,00%)	Flow (+95,00%)
0	20.60000	0.641098	19.34288	21.85712
1	12.64815	0.647007	11.37944	13.91686
2	9.34579	0.650023	8.07117	10.62042
3	8.87037	0.647007	7.60166	10.13908
4	10.39815	0.647007	9.12944	11.66686
5	17.49074	0.647007	16.22203	18.75945
6	29.71963	0.650023	28.44500	30.99425
7	44.15888	0.650023	42.88425	45.43350
8	52.71698	0.653082	51.43636	53.99760
9	57.09346	0.650023	55.81883	58.36808
10	55.96190	0.656184	54.67520	57.24861
11	54.30476	0.656184	53.01806	55.59147
12	53.02857	0.656184	51.74187	54.31528
13	53.49533	0.650023	52.22070	54.76995
14	50.77064	0.644032	49.50777	52.03352
15	49.84259	0.647007	48.57388	51.11130
16	48.29630	0.647007	47.02759	49.56501
17	47.36697	0.644032	46.10410	48.62985
18	48.29358	0.644032	47.03070	49.55645
19	54.84404	0.644032	53.58116	56.10691
20	56.41284	0.644032	55.14997	57.67572
21	53.00000	0.644032	51.73712	54.26288
22	47.68807	0.644032	46.42520	48.95095
23	34.90826	0.644032	33.64538	36.17113

to 2014 with a probability of 95% and it shows a difference between the flow and the flow measurement hour.

On the basis of the statistical analysis, the highest and lowest demands of drinking water were determined. The lowest quantitative demands of water occurred between hours 2:00 and 5:00, and the highest flow period is between hours 8:00 and 11:00 and 19:00 and 21:00. By the technical reason, the highest flow period was established between hours 8:00 and 11:00.

2.3. Sample analysis

Samples were collected in aseptic glass vials with polypropylene cap and silicone septa for THMs analysis. The glass vial was added with sodium thiosulfate as a dechlorination agent and it was fully filled with water leaving no headspace. Free residual chlorine and water temperature were measured *in situ*, immediately after the sample was taken. The samples were transported to the laboratory in a cooler (4˚C). The collected samples were analyzed for THMs which include the total THMs, dichlorobromomethane, trichloromethane, dibromochloromethane, and tribromomethane. The analysis of THMs was conducted according to PN-EN ISO 10301:2002 method using a gas chromatography with an electron capture detector (GC-ECD). The determination range for THMs species was from 0.99 to 250 μg/L. Free residual chlorine was measured using a HACH colorimeter. pH was measured with a WTW pH meter. The temperature was measured with a HANNA electronic thermometer. The parameters, measurement techniques, and equipment of the research are shown in Table 3.

2.4. Statistical methods

Correlation coefficients between the concentration of THMs and temperature, pH, and distance between well meter and tap were assessed by the Pearson's correlation method. This method was used to measure the strength of the relation between the variables. The letter r represents the sample correlation coefficient and P represents the correlation coefficient of the population. Water quality parameters were analyzed using the statistical method (average, standard error, confidence interval, and median) in STATISTICA 10.

3. Results and discussion

3.1. Drinking water quality parameters

The drinking water quality parameters in selected objects for the research period are shown in Table 4. The mean value for temperature in water samples taken from the domestic lines were observed to be higher compared to the water samples taken from the well meter. In samples taken between 2:00 and 5:00, average temperature changes in sampling points from the well meter to the domestic line fluctuated in the range 0.1–4.7˚C and in samples taken between 8:00 and 11:00, the range was lower (0.4–1.1). The significant temperature changes were observed between water samples taken from the domestic lines and water taps. In samples taken between 2:00 and 5:00, average temperature in sampling points from the domestic line to tap water increased from 10.3 to 24.8˚C (Ob4). High tap water temperature was the result of water stagnation in pipes inside the objects during the night period. The average temperature change for samples taken between 8:00 and 11:00 fluctuated in the range 5.4–8.9˚C. For all collected samples, the average level of pH was constant (7.5–7.7). During the research period, the residual of free chlorine was below threshold determination (0.05 mg/L).

Four species of THMs were detected in all the samples. Tables 5 and 6 show the mean value of the concentration of the total THMs, chloroform (TCM), bromoform (TBM), dibromochloromethane (DBCM),

Table 3
Range of parameters in the research

Parameter	Measurement techniques	Measurement equipment
Temperature	PB/15 ed.2:01.07.2009	Electronic thermometer H I 145-20, HANNA
Chlorine free	PB/19 ed.2:01.07.2009	Pocket Colorimeter, HACH
pH	PN-EN ISO 10523:2012	WTW inoLab pH/Cond 740 Set
Dichlorobromomethane	PN-EN ISO 10301:2002	Gas chromatography-electron capture detection (GC-ECD)
Trichloromethane	PN-EN ISO 10301:2002	Gas chromatography-electron capture detection (GC-ECD)
Dibromochloromethane	PN-EN ISO 10301:2002	Gas chromatography-electron capture detection (GC-ECD)
Tribromomethane	PN-EN ISO 10301:2002	Gas chromatography-electron capture detection (GC-ECD)
Sum of THMs	PN-EN ISO 10301:2002	Gas chromatography-electron capture detection (GC-ECD)

Table 4
Drinking water quality parameters in selected objects

Object in WSS	Sampling location	Parameter							
		Samples taken between 2:00 and 5:00				Samples taken between 8:00 and 11:00			
		Temperature (˚C)		pH		Temperature (˚C)		pH	
		Mean (median)	Range	Mean (median)	Range	Mean (median)	Range	Mean (median)	Range
Ob1	Well meter	8.7 (8.5)	3.8–13.3	7.7 (7.6)	7.39–8.12	8.9 (8.4)	5.8–13.9	7.7 (7.6)	7.44–8.19
Ob2	Domestic line	13.4 (13.0)	8.9–17.0	7.7 (7.6)	7.40–8.21	11.1 (11.3)	6.9–15.4	7.7 (7.7)	7.26–8.06
	Tap water	25.9 (25.2)	22.8–31.2	7.6 (7.6)	7.42–8.07	19.9 (20.4)	11.9–27.2	7.7 (7.7)	7.51–8.00
Ob3	Domestic line	8.8 (8.1)	5.4–13.3	7.6 (7.6)	7.45–7.90	8.5 (7.3)	5.6–13.6	7.6 (7.6)	7.36–7.96
	Tap water	20.4 (21.4)	11.7–23.2	7.6 (7.6)	7.47–8.14	17.8 (17.4)	10.8–22.7	7.6 (7.6)	7.42–8.08
Ob4	Domestic line	10.3 (10.0)	6.9–14.4	7.7 (7.7)	7.48–8.08	9.5 (9.5)	6.2–14.7	7.5 (7.7)	7.47–8.01
	Tap water	24.8 (25.2)	21.7–27.0	7.7 (7.6)	7.40–8.81	18.4 (20.2)	11.2–24.2	7.7 (7.7)	7.41–7.99
Ob5	Domestic line	10.9 (10.8)	8.1–14.5	7.7 (7.6)	7.40–8.12	9.8 (9.2)	6.8–13.8	7.7 (7.6)	7.38–8.09
	Tap water	20.5 (21.3)	15.4–24.5	7.6 (7.6)	7.46–8.09	16.9 (16.8)	9.4–24.5	7.7 (7.6)	7.37–8.11
Ob6	Domestic line	9.5 (9.5)	6.1–13.4	7.7 (7.7)	7.51–8.01	9.2 (8.3)	6.0–13.3	7.7 (7.7)	7.47–8.10
	Tap water	18.6 (18.2)	14.4–23.1	7.7 (7.6)	7.45–7.99	14.6 (14.0)	10.7–19.7	7.6 (7.6)	7.22–8.04

and dichlorobromomethane (DCBM) at each sampling point. Chloroform constitutes the major component in THMs. The mean value of chloroform between 2:00 and 5:00 ranged from 5.0 to 6.0 μg/L, and between 8:00 and 11:00, the range is determined on the same level (4.8–6.0 μg/L). The mean value of dibromochloromethane and dichlorobromomethane between 2:00 and 5:00 ranged from 2.8 to 3.4 μg/L and 3.9 to 4.5 μg/L, respectively. In the samples taken between 8:00 and 11:00, the concentration of dibromochloromethane and dichlorobromomethane ranged from 3.0 to 3.5 μg/L and from 3.9 to 4.5 μg/L, respectively. The mean value of bromoform between 2:00 and 5:00 such as between 8:00 and 11:00 ranged from 1.0 to 1.2 μg/L. The share of THMs species in drinking water samples from the research objects is similar regardless of the water flow. Some examples of THMs species distribution are shown in Fig. 1.

The highest concentration reported for chloroform was (TCM) 35–41%, and lowest for bromoform (TBM) 8–9%. Dibromochloromethane (DBCM) and dichlorobromomethane (DCBM) were as follows: 21–25% and 28–32%, respectively. The concentration of THMs in water samples taken during the research period was between 5.5 and 19.4 μg/L, and it met the USEPA and Polish standards [15,16].

3.2. Effect of flow

Using the Pearson's correlation method, a small relationship ($r = 0.1242$) was obtained between the occurrence of THMs in water samples taken from research objects and water flow in the distribution system as shown in Table 7. However, the results of the research found out that after night stagnation of water in pipes, the average concentration of the total THMs in water samples taken from the well meter was insignificantly higher (about 1.0 μg/L) than in water samples taken from the domestic lines in objects 2 and 3 and from taps in objects 2 and 4 (Fig. 2). The average concentration of the total THMs was similar in water from other sampling points.

The average concentration of the total THMs in water samples taken from the well meter was lower (in the range from 0.3 to 1.5 μg/L) than in water samples taken from the domestic lines and taps in other objects (Fig. 3).

The concentration of THMs in samples taken between 2:00 and 5:00 when water stagnation and low flow in the distribution system proved that the concentration of THMs tended to be smaller. This observation was confirmed by studies conducted by other researches [1,2,4,7,30].

Table 5
Mean value of the concentration of total THMs, chloroform (TCM), bromoform (TBM), dibromochloromethane (DBCM), and dichlorobromomethane (DCBM) at sampling points in samples taken between 2:00 and 5:00

		Dichlorobromomethane		Trichloromethane		Dibromochloromethane		Tribromomethane		Total THMs	
Object in WSS	Sampling location	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Ob1	Well meter	4.1 (4.3)	1.2–5.9	5.6 (5.5)	1.6–8.9	3.2 (3.0)	1.8–4.9	1.1 (1.0)	0.99–3.2	14.0 (12.7)	8.5–17.1
Ob2	Domestic line	4.0 (4.3)	1.1–6.2	5.1 (5.2)	1.5–7.8	3.3 (3.4)	2.0–4.9	1.1 (1.0)	0.99–3.2	13.5 (12.3)	7.8–17.8
	Tap water	4.1 (4.2)	1.0–6.0	5.0 (4.5)	3.0–7.5	2.9 (3.0)	1.2–4.1	1.0 (1.0)	0.99–3.8	13.0 (11.3)	6.5–16.9
Ob3	Domestic line	4.4 (4.3)	1.0–6.5	5.3 (5.5)	1.0–9.8	3.4 (3.4)	1.1–4.6	1.2 (1.0)	0.99–2.9	14.3 (12.6)	7.5–18.4
	Tap water	4.0 (4.1)	1.0–5.6	5.2 (4.9)	2.5–7.8	2.8 (3.1)	1.0–4.2	1.1 (1.0)	0.99–1.9	13.1 (11.2)	7.3–16.3
Ob4	Domestic line	3.9 (3.8)	1.0–5.6	4.3 (4.2)	3.2–7.0	3.1 (3.2)	1.7–4.7	1.1 (1.0)	0.99–3.2	12.4 (11.5)	7.1–16.1
	Tap water	4.5 (4.4)	1.0–6.4	5.2 (4.9)	1.8–8.0	3.2 (3.3)	1.8–4.7	1.2 (1.0)	0.99–3.0	14.1 (12.6)	8.6–18.3
Ob5	Domestic line	4.1 (4.2)	1.3–6.7	6.0 (6.3)	1.8–9.8	3.1 (3.1)	1.8–4.7	1.1 (1.0)	0.99–2.8	14.3 (12.9)	8.7–19.4
	Tap water	4.1 (4.4)	1.2–6.7	5.7 (5.7)	1.5–10.0	3.2 (3.4)	1.8–4.3	1.1 (1.0)	0.99–2.6	14.1 (12.4)	9.0–19.1
Ob6	Domestic line	4.0 (4.2)	1.2–6.2	5.8 (5.7)	1.5–9.6	3.0 (2.9)	1.7–4.6	1.1 (1.0)	0.99–3.2	13.9 (12.2)	7.7–18.0
	Tap water	4.3 (4.2)	1.1–6.6	5.5 (5.5)	1.6–9.4	3.2 (2.9)	2.1–4.9	1.2 (1.0)	1.0–3.1	14.2 (12.4)	8.0–18.9

Table 6
Mean value of the concentration of total THMs, chloroform (TCM), bromoform (TBM), dibromochloromethane (DBCM), and dichlorobromomethane (DCBM) at sampling points in samples taken between 8:00 and 11:00

		Dichlorobromomethane		Trichloromethane		Dibromochloromethane		Tribromomethane		Total THMs	
Object in WSS	Sampling location	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Ob1	Well meter	4.1 (4.3)	1.3–6.0	4.8 (4.6)	2.0–7.4	3.3 (3.6)	2.1–4.5	1.0 (1.0)	1.0–1.4	13.2 (11.4)	8.8–17.2
Ob2	Domestic line	4.4 (4.6)	1.0–6.2	5.1 (5.7)	1.6–8.1	3.5 (3.7)	1.7–4.6	1.2 (1.0)	1.0–3.4	14.2 (12.9)	5.5–18.1
	Tap water	4.5 (4.7)	1.0–6.1	5.4 (5.3)	1.9–8.6	3.4 (3.3)	1.7–5.4	1.2 (1.0)	1.0–3.7	14.5 (12.8)	9.1–17.3
Ob3	Domestic line	3.9 (4.1)	1.0–6.1	5.4 (6.2)	1.4–7.6	3.1 (3.3)	1.7–5.1	1.1 (1.0)	1.0–3.6	13.5 (12.0)	9.4–17.5
	Tap water	4.3 (4.4)	1.0–6.3	5.8 (6.2)	2.1–8.4	3.0 (3.1)	1.6–4.4	1.1 (1.0)	1.0–2.5	14.2 (12.1)	7.4–17.9
Ob4	Domestic line	3.9 (4.2)	1.2–5.6	5.6 (5.7)	1.6–8.7	3.1 (3.2)	1.8–4.8	1.2 (1.0)	1.0–3.7	13.8 (12.9)	10.1–16.9
	Tap water	4.4 (4.3)	1.0–6.2	4.8 (4.7)	2.2–8.0	3.2 (3.6)	1.6–5.2	1.2 (1.0)	1.0–3.3	13.6 (12.1)	8.7–17.8
Ob5	Domestic line	4.3 (4.6)	1.2–6.7	5.7 (5.8)	1.9–8.7	3.3 (3.4)	2.1–4.8	1.1 (1.0)	1.0–2.9	14.4 (12.5)	10.1–19.2
	Tap water	4.3 (4.5)	1.2–6.4	5.8 (6.3)	1.6–8.5	3.5 (3.5)	2.1–4.5	1.2 (1.0)	1.0–3.2	14.8 (13.4)	11.0–18.2
Ob6	Domestic line	4.2 (4.4)	1.1–6.5	5.7 (6.2)	1.6–8.5	3.3 (3.4)	2.1–4.6	1.2 (1.0)	1.0–3.2	14.4 (13.2)	8.3–18.7
	Tap water	4.4 (4.5)	1.4–6.6	6.0 (6.5)	1.3–9.5	3.2 (3.1)	2.2–4.6	1.2 (1.0)	1.0–3.4	14.8 (13.8)	9.7–18.9

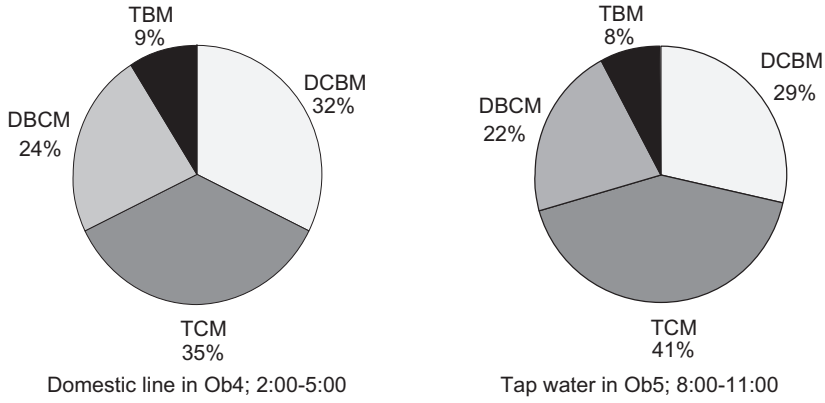

Fig. 1. Distribution of THMs species.

Table 7
Relationship between concentration of a dependent variable THMs with independent variables from the water distribution system in the selected zone

THMs concentration with independent variable ($N = 336$)	Pearson (r)	P
Material	0.0646	0.238
Flow	0.1242	0.023
Length	0.0613	0.521

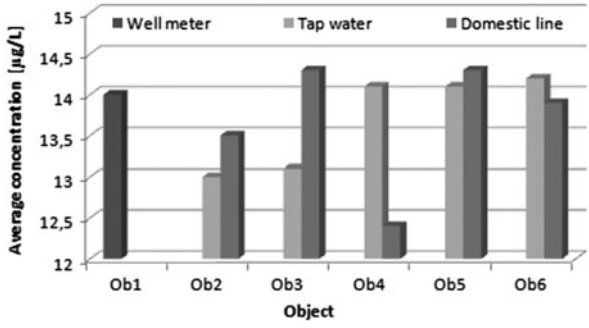

Fig. 2. Average concentration of the total THMs in water samples taken between 2:00 and 5:00.

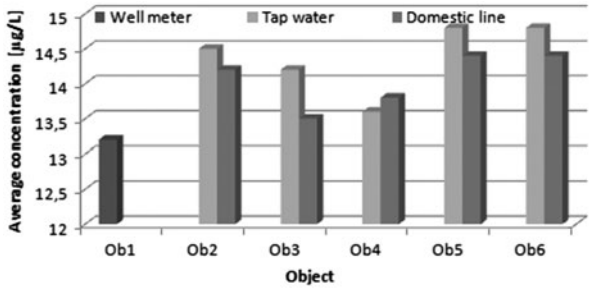

Fig. 3. Average concentration of the total THMs in water samples taken between 8:00 and 11:00.

3.3. Effect of pipes' material

For the determination of material impact on the concentration of THMs in drinking water, the selected object has different material characteristics. The water is transported to the well meter through steel pipes. From the well meter, water is transported to some public schools, social welfare buildings, and low-rise buildings by polyethylene (PE) pipes. In contrast, steel pipes are used to transport water from the well meter to public hospitals and high-rise buildings. Also, the materials of domestic lines are diversified. For the public school, low-rise building, and high-rise building, the domestic line is made of steel. The material of the domestic line in the hospital and social welfare building is PE. In majority of objects, water installation inside the buildings (tap water) is made of steel, only in the public hospital the pipes are PE. The Pearson's method of correlation was applied and a small relationship ($r = 0.0646$) was obtained between the occurrence of THMs in drinking water and pipes material used in the water distribution system in the selected zone and is shown in Table 7.

The research [31] conducted in a distribution system simulator showed that the ranking of the formation of THMs in different pipe materials was: first, plastics and second, steel. Investigation presented in the article in the real distribution system demonstrated a slight relationship between the occurrence of THMs in drinking water and the pipe material. The study proved that in the real distribution system, the levels of THMs in tap water are more dependent on other factors.

3.4. Effect of length of pipes

Attempts were made to determine the effect of distance between the well meter and the particular object on the concentration of THMs in the distribution system. Effect of distance from the well meter to selected objects in the distribution system is an indirect way of measuring the contact time between a chlorine dose and THMs precursors. The well meter is the beginning point in the researched water supply zone. The selected objects are located at different distances and directions from the well meter as shown in Table 1. The longest distance (80.4 m) is between the well meter and the social welfare building. The public school is situated on the shortest distance (33.0 m) from the well meter.

The longest domestic line is made of PE in the public hospital—10.5 m and the shortest—3.1 m made of steel in the high-rise building. From the domestic line to tap, the longest plumbing (steel pipes) was in the high-rise building—22.4 m length. It is not surprising that the shortest plumbing (4.7 m) is in the low-rise building. Fig. 4 illustrated the average concentration of THMs species in tap water samples taken from the research objects.

In all cases, the distribution of THMs species is similar, and so chloroform (TCM) was present in the highest concentration and bromoform (TBM) in the lowest. Using the Pearson's correlation method, a

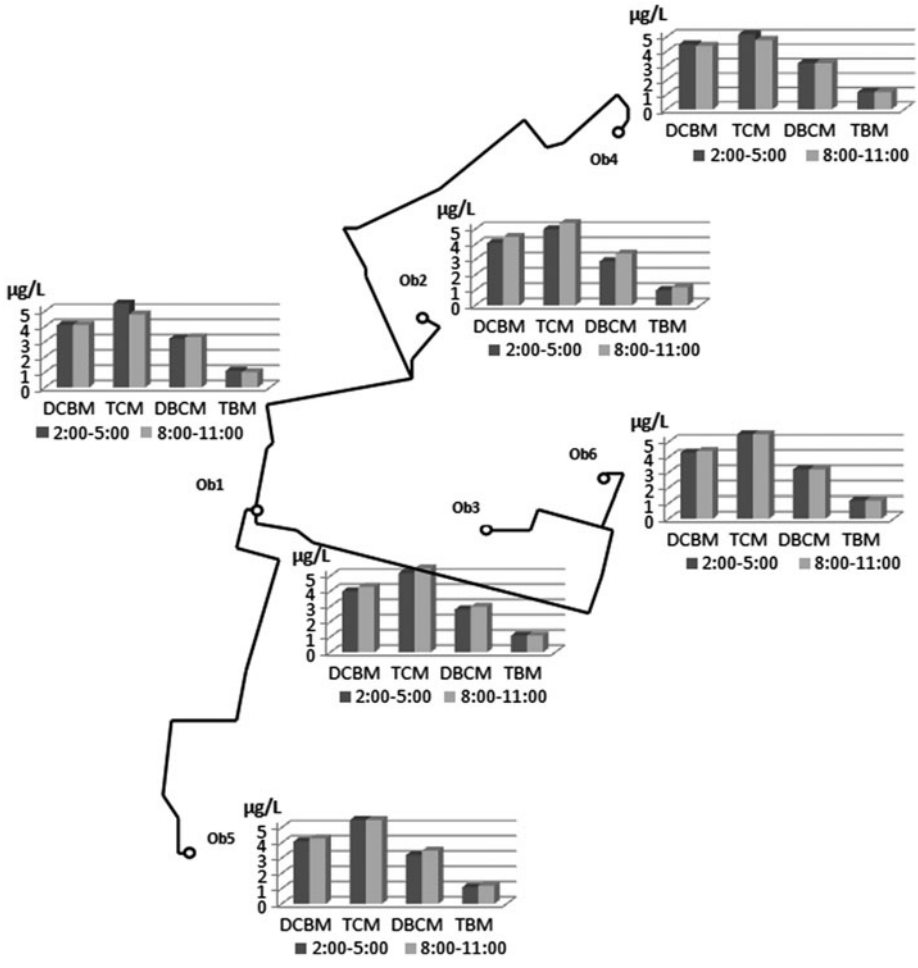

Fig. 4. Spatial location of research objects and the distribution of THMs species in tap water samples.

small relationship ($r = 0.0613$) was obtained between the occurrence of THMs in water samples taken from research objects and distances between the well meter and selected objects and are shown in Table 7.

The observations from full-scale treatment plants and distribution systems [1,2] have shown that the level of THMs formation in chlorinated distribution systems are expected to be highest where the contact time between water and free chlorine is the longest. The increase in the concentration of THMs in water samples taken between 8:00 and 11:00 was noticed even for the object (Ob2) located in the shortest distance from the well meter. For the water samples taken between 2:00 and 5:00, the results were inconclusive because only in two locations (Ob3 and Ob5) the increase in the level of THMs was observed.

4. Conclusions

The total concentration of THMs was very low (ranged from 5.5 to 19.4 μg/L) in tap water in the selected water supply zone. Chloroform (ranged from 1.3 to 10.0 μg/L) and dichlorobromomethane (ranged from 1.0 to 6.7 μg/L) were the major THMs species identified at the sampling points. Bromoform and dibromochloromethane were usually detected at levels ranging from 0.99 to 3.7 μg/L and from 1.0 to 5.2 μg/L, respectively. There was only a very small relationship between the concentration of THMs and selected parameters: properties of pipes material, water flow in the distribution system, and the distance between the well meter and particular object in the distribution system. The results showed that the water temperature had also no significant effect on the formation of THMs, and in this case, others factors, i.e. TOC, might have an influence on the formation of THMs.

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