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FACTORS DETERMINING THE OPTICAL PROPERTIES OF UNDERGROUND WATER INTENDED FOR HUMAN CONSUMPTION

CZYNNIKI WARUNKUJĄCE WŁAŚCIWOŚCI OPTYCZNE WÓD PODZIEMNYCH PRZEZNACZONYCH DO SPOŻYCIA

Abstract: The optical properties of water (color and turbidity) and the content of iron and manganese compounds were determined in a multi-year study of underground water in 1990–2004. Water samples were collected from 12 intake monitoring sites in the following regions: Lower Vistula Valley, Zulawy Wislane – Vistula Delta Plain, Starogard Lakeland and Ilawa Lakeland. The maximum allowable turbidity levels (1 NTU) were exceeded in raw water samples, which required treatment. The optical parameters of water were affected by iron and manganese concentrations. Water samples with, a high iron content were collected from all investigated regions. The highest iron content of raw water samples was noted in Sztum (2.50 to 6.90 mg $\cdot$ dm^{-3} total Fe), and the lowest – in Malbork (0.05 to 0.20 mg $\cdot$ dm^{-3} total Fe). The highest manganese concentrations (0.72 to 1.72 mg $\cdot$ dm^{-3}) were reported in raw water samples collected in the Zulawy Water Mains. Manganese levels ranged from 0.19 to 0.40 mg $\cdot$ dm^{-3} Mn in Sztum, and from 0.14 to 0.30 mg $\cdot$ dm^{-3} Mn in Kwidzyn. The lowest manganese concentrations were reported in raw water samples from Tertiary and Cretaceous water-bearing horizons. These samples did not require treatment.

In most cases, the flow of water through the distribution network modified the parameters of treated water. This is an adverse phenomenon, as the final product supplied to end-users may not comply with standard requirements. For this reason, optical parameters and the manganese and iron content of potable water have to be monitored regularly between the point of water intake and the end-user.

Keywords: color, turbidity, iron, manganese, water-bearing horizons, water quality

Introduction

Underground water intended for human consumption is subject to special protection, and the physical and chemical composition of water has to be monitored regularly to

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ensure that the consumers are supplied with safe potable water. In some cases, special measures have to be initiated instantly to protect both the source and the quality of water [1, 2]. According to the WHO in 1998, water is safe for human health if it meets basic sanitation requirements. Water, the indispensable element of life, has to be supplied in a satisfactory quantity and quality [3, 4]. When evaluating the quality of water, consumers rely on its organoleptic properties, in particular the optical qualities of water. Water characterized by high turbidity and an intense color which is attributed mostly to high concentrations of iron and manganese compounds, is regarded as unsafe for consumption. Water color may also be affected by the presence of colored organic substances found in the humus fraction of soil. Those substances are a potential source of energy and carbon for the microorganisms dwelling in potable water. The presence of such substances in the distribution network increases the risk of pipeline corrosion [5–7]. Yet most importantly, organic compounds found in the water mains may pose a direct health hazard [3]. Water marked by high turbidity may protect microorganisms from disinfecting agents, and it may stimulate the growth of bacteria. Iron is a natural and a commonly occurring component of underground water, and it is found in various combinations and forms. The above is caused by the continuous dissolution of minerals and the presence of carbon dioxide in water. In general, underground water is deprived of oxygen, which is why iron is found mostly in the oxidation state of +2 (Fe^{+2}) in the form of iron bicarbonate and iron sulfate. In the presence of oxygen, the above compounds are hydrolyzed, producing iron hydroxide. Iron deteriorates the taste properties of water excessive iron levels may have an adverse effect on various technological processes and may stimulate the growth of iron-oxidizing and manganese--oxidizing bacteria [5, 7, 8].

Manganese is an essential trace element, which is needed for the proper functioning of living organisms [8], yet it may also exert a toxic effect. Excess manganese causes damage to parenchymatous organs and disrupts iron metabolism [8, 9]. In underground water, manganese occurs mostly with iron in the form of bicarbonate and sulfate. Manganese is an element with multiple oxygen states which affects the water treatment process. In water, manganese is oxidized by chloride. When oxidized to Mn^{+4}, it forms insoluble manganese dioxide (MnO_2) which causes brown spots in laundry items and industrial products. Excess manganese levels deteriorate the organoleptic properties of water and, similarly to iron, they may have an adverse effect on selected technological processes. The presence of manganese in potable water may lead to sediment formation in the water distribution network [10, 11].

This paper presents the results of a multi-year study investigating the factors responsible for changes in water turbidity and color, and in the concentrations of iron and manganese between the point of water intake and the end-user.

Materials and methods

The optical properties of water (color and turbidity), iron and manganese concentrations were analyzed in 1990–2004 in samples of underground water from 12 intake monitoring sites in four Polish mesoregions: Lower Vistula Valley, Zulawy

Wislane – Vistula Delta Plain, Starogard Lakeland and Ilawa Lakeland (Table 1). The quality of water in the studied regions was evaluated in view of the water source (water intake), the applied treatment method (treatment plant), the water distribution network (end-user) and the depth of the water-bearing horizon. The studied monitoring sites were diversified with regard to their geological structure and the number and depth of wells.

Table 1

Characteristic features of potable water intakes investigated in the study

Mesoregion	Intake	Population supplied in 2004	Water-bearing horizons	Number of wells/ Well depth [well/m]	Piping material	Treatment process
Lower Vistula Valley	Male Walichnowy	833	Cretaceous	1/129 1/101.5	cast iron, steel, PVC	aeration
	Wielkie Walichnowy	850	Cretaceous	1/110	cast iron, asbestos-cement	aeration
	Gniew	7 100	Cretaceous Tertiary	1/130 1/120	cast iron, asbestos-cement	aeration, deferrisation
	Gardeja	2 864	Quaternary	1/57 1/60	cast iron, asbestos-cement	aeration, deferrisation
	Kwidzyn Kamionka	25 080	Cretaceous Tertiary	1/231 3/180,161, 163	cast iron, asbestos-cement	aeration, deferrisation
Vistula Zulawy	Zulawy Water Mains	60 000	Cretaceous Tertiary	26/35-80 1/250	cast iron, PVC, asbestos-cement	aeration, deferrisation
	Malbork	40 000	Cretaceous Tertiary	5/260 3/103	cast iron, PVC, asbestos-cement	aeration
Starogard Lakeland	Tczewskie Laki	692	Cretaceous Tertiary	1/84 1/96	cast iron, steel	aeration, deferrisation
	Tczew-intakes: – Park – Motlawa	65 000	Cretaceous Quaternary--Tertiary Tertiary Cretaceous	3/150-180 5/92-105.5 10/93-110 1/150	cast iron, PVC, asbestos-cement	aeration, deferrisation, manganese removal, biological ammonia removal
	Starogard Gdanski Wierzyca	48 328	Quaternary	8/72-80	cast iron, steel, PVC	aeration, deferrisation
Ilawa Lakeland	Sztum	15 260	Quaternary Tertiary	4/60-80 1/155	cast iron, PVC, asbestos-cement	aeration
	Dzierzgon	7 100	Tertiary	2/168, 175	cast iron, PVC, asbestos-cement	aeration

The analyzed sites were situated in Quaternary formations with a depth of 35–80 m, as well as Tertiary and Cretaceous formations with a depth of 260 m. Water purity was studied in the process of water production, treatment and distribution. In view of the above, the study accounted for the type of piping material applied in a given distribution network. The geological structure of the investigated regions was determined based on the statements on water management conditions supplied by mains operators as well as on hydrological reports of underground water resources of the Polish Geological Institute [10, 11]. The following optical properties of the collected water samples were studied: turbidity – by spectrophotometry at a wavelength of 420 nm [12], color – according to the platinum-cobalt scale [13], iron levels – by spectrophotometry with phenanthroline [14], and manganese levels – by the colorimetric method with persulfate at a wavelength of 525 nm [15]. To compare changes in the physical and chemical composition of water between the point of water intake and the end-user, analytical samples were collected from: the water intake (raw water), treatment station (treated water) and the distribution network (end-user). The average values noted throughout the experimental period were compared with the maximum allowable concentrations (MAC) in view of the characteristic features of monitoring sites in each region (Table 1), including hydrogeological conditions, the applied treatment technology and pipeline material. Those factors were deployed in a statistical analysis to determine the presence of correlations, and in a one-factor analysis of variance (ANOVA) with the use of Duncan's test, at a significance level of $p \leq 0.05$. The results were processed mathematically and statistically with the use of the StatSoft Statistica 7.1 application.

Results

The results of the multi-year study indicate that excessive manganese and iron levels deteriorated the organoleptic properties of water such as turbidity and color. The turbidity of the analyzed samples ranged from 0.0 to 40 NTU, and significant variations were reported both within and between the studied regions, as demonstrated by the coefficients of variation (cv) reaching from 0 % in Male Walichnowy to 181 % in Malbork (Table 2). The highest turbidity was reported in raw water samples from Quaternary deposits in Sztum (28.0 NTU), Starogard Gdanski (15.0 NTU), Zulawy Water Mains – ZWM (26.4 NTU) and Gardeja (14.2 NTU). Monitoring sites were situated in four regions, and the variations in the quality of the collected water samples were due to the specific environmental factors in each studied region. Raw water samples obtained from shallower water-bearing horizons were characterized by poorer optical properties. Increased color values were determined in samples from Quaternary (Q) and Quaternary-Tertiary (QT) horizons, and the maximum allowable concentrations of 15 $mg \cdot dm^{-3}$ Pt were exceeded in selected sites. The above applies to water samples from Sztum with an average color value of 28.0 $mgPt \cdot dm^{-3}$, and from ZWM with an average color value of 24 $mgPt \cdot dm^{-3}$. In both areas, the water mains are supplied from the QT horizon (Table 2).

As shown by the data in Table 1, raw water samples obtained from shallower water-bearing horizons (at a depth of around 30 m) were characterized by less satisfactory optical properties, mainly due to the high concentrations of iron and manganese compounds which affected both water turbidity and color. Underground water samples contained organic iron, and total Fe concentrations ranged from 0.05 to 6.9 $mg \cdot dm^{-3}$. Average total $Fe_{.}$ levels were determined in the range of 0.11 $mg \cdot dm^{-3}$

Table 2

Statistical characteristics of the turbidity and color parameters of raw water samples collected from selected intakes in the Ilawa Lakeland, Starogard Lakeland, Vistula Zulawy and the Lower Vistula Valley in 1990–2004

Mesoregion	Intake	Turbidity [NTU]				Color [mgPt · dm^{-3}]			
		Mean	Min	Max	*cv* [%]	Mean	Min	Max	*cv* [%]
Ilawa Lakeland	Dzierzgon	6.5	0.0	15.0	82	12.0	10.0	15.0	58
	Sztum	28.0	9.0	40.0	49	28.0	15.0	40.0	31
Starogard Lakeland	Starogard Gdanski	6.0	6.0	16.0	83	15.0	7.0	20.0	51
	Tczew	7.0	4.0	10.0	5	4.0	1.0	5.0	26
	Tczewskie Laki	3.2	0.0	5.0	60	4.7	1.0	16.5	109
Vistula Zulawy	Malbork	1.3	0.0	7.0	181	7.0	1.0	13.0	58
	Zulawy Water Mains	26.4	15.0	35.0	24	23.9	20.0	28.0	9
Lower Vistula Valley	Gardeja	14.2	5.0	30.0	65	20.7	12.5	30.0	36
	Gniew	9.4	2.0	19.0	32	5.0	2.0	6.5	35
	Kwidzyn	12.4	7.0	30.0	90	21.1	15.0	25.0	21
	Male Walichnowy	2.0	2.0	2.0	0	2.5	2.0	3.0	28
	Wielkie Walichnowy	2.7	2.0	3.0	21	2.0	1.0	3.0	50

in Malbork to 5.64 mg · dm^{-3} in Sztum. The maximum allowable concentrations (MAC) of iron – MAC_{Fe} = 0.20 mg · dm^{-3} Regulation of the Health Minister of 2007 [16] were exceeded in all raw water samples (excluding Malbork) which required treatment (Table 3).

Table 3

Statistical characteristics of iron and manganese concentrations in raw water samples collected in the Ilawa Lakeland, Starogard Lakeland, Vistula Zulawy and the Lower Vistula Valley in 1990–2004

Mesoregion	Intake	Iron [mg total Fe · dm^{-3}]				Manganese [mgMn · dm^{-3}]			
		Mean	Min	Max	*cv* [%]	Mean	Min	Max	*cv* [%]
Ilawa Lakeland	Dzierzgon	0.42	0.30	0.80	29	0.150	0.080	0.220	67
	Sztum	5.64	2.50	6.90	39	0.280	0.190	0.400	29
Starogard Lakeland	Starogard Gdanski	2.00	1.75	2.40	14	0.190	0.150	0.270	21
	Tczew	0.24	0.10	0.45	38	0.013	0.001	0.040	130
	Tczewskie Laki	0.46	0.20	0.74	4	0.017	0.001	0.080	150
Vistula Zulawy	Malbork	0.11	0.05	0.20	55	0.020	0.000	0.080	150
	Zulawy Water Mains	3.79	3.27	6.23	26	1.220	0.720	1.720	25
Lower Vistula Valley	Gardeja	4.00	2.90	4.90	26	0.260	0.200	0.400	23
	Gniew	0.70	0.30	1.10	51	0.050	0.030	0.060	165
	Kwidzyn	3.55	3.05	4.05	22	0.180	0.140	0.300	83
	Male Walichnowy	0.40	0.10	0.50	58	0.000	0.000	0.000	0
	Wielkie Walichnowy	0.33	0.30	0.40	18	0.001	0.000	0.002	0

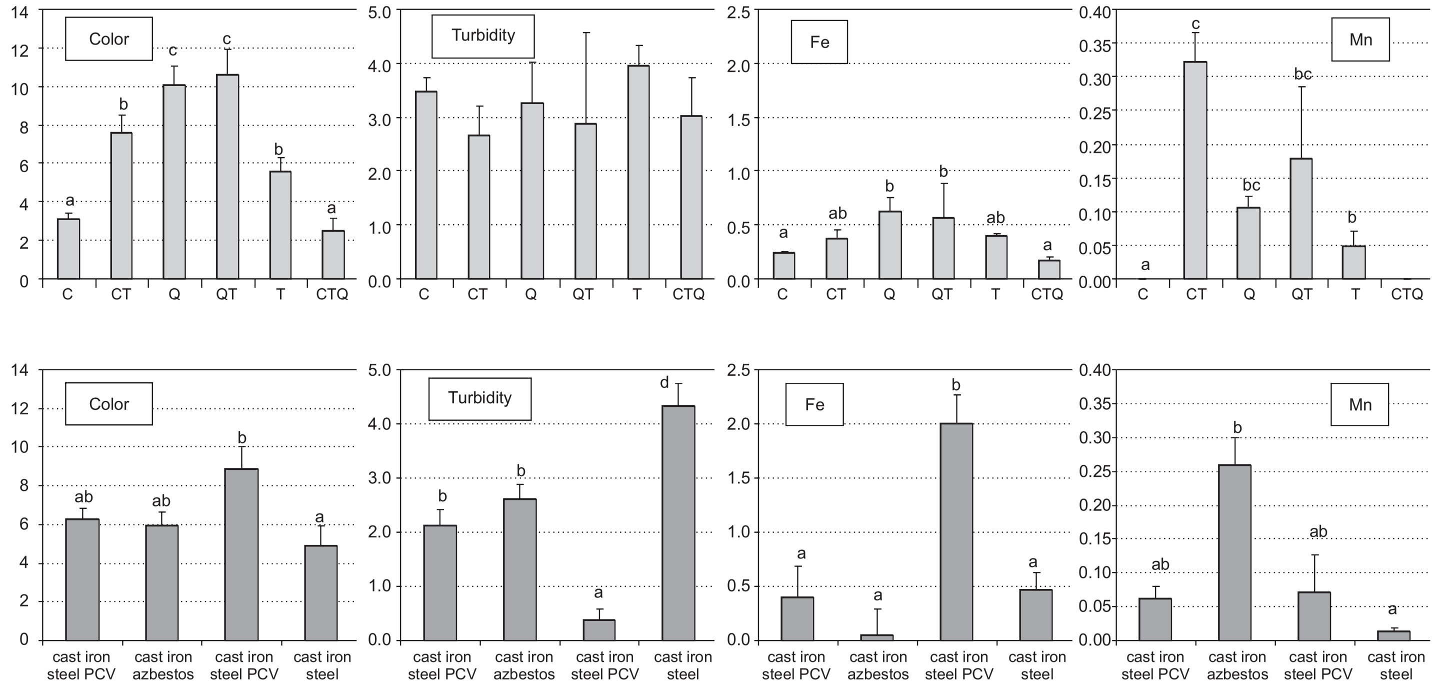

Fig. 1. Changes in color [mgPt · dm^{-3}], turbidity (NTU), total iron and manganese contents [mg · dm^{-3}] in raw water samples, subject to the water-bearing horizon (C – Cretaceous, T – Tertiary, Q – Quaternary) and in the treated water samples, subject to the applied pipeline material. Vertical ranges indicate the standard error of the mean (+SE). Identical letters (a, b) indicate groups of homogenous means (that do not produce significant differences in Duncan's test, ANOVA, post-hoc, $p < 0.05$)

The maximum allowable concentrations of manganese in raw water samples were exceeded in selected monitoring sites in every studied region [9]. The highest manganese levels between 0.72 and 1.72 mg · dm^{-3} were reported in ZWM (Table 3). Manganese concentrations reached from 0.19 to 0.40 mgMn · dm^{-3} in Sztum, and from 0.14 to 0.30 mgMn · dm^{-3} in Kwidzyn. The lowest manganese levels were determined in raw water samples from Male Walichnowy, Wielkie Walichnowy, Tczew, Tczewskie Laki and Malbork.

The characteristic features of the studied raw water samples were mirrored by the results of statistical analyses carried out with the use of Duncan's test at $p \leq 0.05$ (Fig. 1). Test results indicate that raw water samples collected from Cretaceous, Tertiary and Quaternary (CTQ) horizons formed a statistically homogenous group with the lowest iron concentrations (a) in comparison with Quaternary (b) and Tertiary--Quaternary (c) horizons.

The highest correlations were determined between the turbidity of raw water samples and their iron ($r = 0.83$) and manganese ($r = 0.54$) content. The effect of color on water turbidity ($r = 0.71$) was also accounted for in the evaluation of raw water quality.

The applied treatment methods alter the chemical composition and the optical properties of water. In selected monitoring stations, treatment minimized the level of pollutants which affect water color, and the relevant reduction ranged from 17 % in Kwidzyn to 63 % in Starogard Gdanski. In several sites, including Wielkie Walichnowy, Male Walichnowy and Tczewskie Laki, treatment enhanced water color (Table 4). The above was attributed to the type of pipeline material (cast iron, steel) and the condition of the distribution network.

Table 4

Statistical characteristics of the turbidity and color parameters of treated water samples collected in the Ilawa Lakeland, Starogard Lakeland, Vistula Zulawy and the Lower Vistula Valley in 1990–2004

Mesoregion	Intake	Turbidity [NTU]				Color [mgPt · dm^{-3}]			
		Mean	Min	Max	*cv* [%]	Mean	Min	Max	*cv* [%]
Ilawa Lakeland	Dzierzgon	2.2	0.0	5.0	81	5.0	1.0	10.0	72
	Sztum	1.2	0.0	5.0	174	11.1	3.0	18.0	39
Starogard Lakeland	Starogard Gdanski	1.7	1.0	3.0	32	5.5	3.0	10.0	47
	Tczew	0.2	0.0	1.0	70	2.1	1.0	2.5	47
	Tczewskie Laki	3.2	0.0	5.0	57	6.8	4.0	16.5	83
Vistula Zulawy	Malbork	0.7	0.0	5.0	140	8.6	5.0	15.0	44
	Zulawy Water Mains	1.5	0.0	3.0	82	12.6	5.0	17.0	34
Lower Vistula Valley	Gardeja	1.0	0.0	1.0	97	9.7	5.0	20.0	46
	Gniew	3.9	2.0	5.0	35	3.4	2.0	5.0	30
	Kwidzyn	0.2	0.0	1.5	152	17.5	5.0	30.0	39
	Male Walichnowy	3.1	1.0	5.0	57	3.0	1.0	5.0	40
	Wielkie Walichnowy	1.6	0.0	5.0	49	2.7	2.0	5.0	46

The above could be due to the applied treatment method which involved mostly water aeration (deferrization was used additionally only in Tczewskie Laki). The effectiveness of treatment in minimizing water turbidity could suggest a high content of dissolved humus compounds which were relatively easily decomposed.

Water treatment involves the removal of iron and manganese, although in raw water, manganese is found in much lower concentrations than iron. In Kwidzyn, water turbidity was effectively minimized owing to the use of a treatment method that involved deferrization.

The majority of raw water samples required treatment to remove excess iron. In Sztum, average iron concentrations were reduced from 5.64 mg total Fe · dm^{-3} in raw water to 0.18 mg total Fe · dm^{-3} in treated water, and the respective reduction in Gardeja was from 4.00 to 0.10 mg total Fe · dm^{-3}. Iron levels were lowered to the MAC limit of 0.20 mg · dm^{-3} (Table 5) only in selected treatment stations. MAC levels for iron were exceeded in, among others, Dzierzgon (0.37 mg total Fe · dm^{-3}), Starogard Gdanski (0.45 mg total Fe · dm^{-3}), Tczewskie Laki (0.30 mg total Fe · dm^{-3}) and Kwidzyn (0.36 mg total Fe · dm^{-3}).

Table 5

Statistical characteristics of iron and manganese concentrations in treated water samples in the Ilawa Lakeland, Starogard Lakeland, Vistula Zulawy and the Lower Vistula Valley in 1990–2004

Mesoregion	Intake	Iron [mg total Fe · dm^{-3}]				Manganese [mgMn · dm^{-3}]			
		Mean	Min	Max	*cv* [%]	Mean	Min	Max	*cv* [%]
Ilawa Lake-land	Dzierzgon	0.37	0.20	0.50	21	0.015	0.070	0.150	153
	Sztum	0.18	0.04	0.30	72	0.100	0.040	0.160	57
Starogard Lakeland	Starogard Gdanski	0.45	0.10	0.80	90	0.069	0.170	0.200	117
	Tczew	0.10	0.03	0.20	83	0.000	0.000	0.003	143
	Tczewskie Laki	0.30	0.20	0.50	47	0.002	0.000	0.005	110
Vistula Zulawy	Malbork	0.10	0.05	0.22	70	0.010	0.000	0.040	200
	Zulawy Water Mains	0.20	0.03	0.35	68	0.200	0.010	0.400	4
Lower Vistula Valley	Gardeja	0.10	0.06	0.30	122	0.145	0.020	0.180	80
	Gniew	0.23	0.09	0.80	76	0.018	0.000	0.038	0
	Kwidzyn	0.36	0.05	1.20	108	0.078	0.010	0.118	7
	Male Walichnowy	0.20	0.10	0.85	68	0.000	0.000	0.000	0
	Wielkie Walichnowy	0.23	0.15	0.30	31	0.001	0.000	0.003	300

The correlations between the parameters of treated water samples were lower than between those of raw water samples. The above seems to be an obvious conclusion as pollutants are eliminated in the treatment process. Water treatment could also affect the concentrations of compounds that cause turbidity at the point of intake. The value of the correlation coefficient r = –0.46 also provides indirect evidence that the turbidity of treated water decreases over time. The depth of water-bearing horizons had a significant influence on treatment efficiency as regards turbidity parameters (r = –0.25). Physical and chemical factors had a negligent effect on the total iron content of treated water samples. The above results are not surprising since the physical and chemical composition of water was actively modified in the treatment process.

The flow of water via the distribution network affects water quality parameters which vary subject to the size and the length of mains pipeline, the speed with which water reaches the end-user, and the applied construction material. The chemical composition of water distributed via the network is an important consideration as it guarantees its chemical stability. Water quality can affect the network and vice versa, and this fact is always reflected in the quality of water supplied to end-users. The above is illustrated by selected color and turbidity parameters as well as iron and manganese concentrations in samples of mains water, as shown in Tables 6 and 7. In Kwidzyn, the color of mains water samples was enhanced in comparison with the samples collected from the treatment station, resulting in an increase from 17.5 mgPt $\cdot$ dm^{-3} to 22.0 mgPt $\cdot$ dm^{-3}, respectively. Similar results were noted in Dzierzgon, where an increase of 140 % was reported, as well as in Wielkie Walichnowy (51.8 %). The above results were clearly affected by the turbidity of mains water. As regards Zulawy, the average values were in the range of 0.2 NTU to 0.6 NTU (Table 6).

Table 6

Statistical characteristics of the turbidity and color parameters of mains water samples collected in the Ilawa Lakeland, Starogard Lakeland, Vistula Zulawy and the Lower Vistula Valley in 1990–2004

Mesoregion	Intake	Turbidity [NTU]				Color [mgPt $\cdot$ dm^{-3}]			
		Mean	Min	Max	*cv* [%]	Mean	Min	Max	*cv* [%]
Ilawa lakeland	Dzierzgon	2.5	0.0	5.0	100	10.2	3.0	12.0	56
	Sztum	2.5	0.0	10.0	86	7.8	5.0	10.0	37
Starogard Lakeland	Starogard Gdanski	5.5	5.0	6.0	15	5.3	4.0	6.0	8
	Tczew	0.4	0.4	1.0	77	1.8	1.0	2.5	53
	Tczewskie Laki	2.4	0.5	8.0	103	3.6	3.0	4.0	40
Vistula Zulawy	Malbork	0.2	0.0	1.0	240	5.5	0.0	10.0	60
	Zulawy Water Mains	0.6	0.0	3.0	168	11.1	6.0	15.0	24
Lower Vistula valley	Gardeja	1.0	0.0	2.0	200	9.5	5.0	15.0	37
	Gniew	3.2	1.0	5.0	59	3.7	1.0	5.0	46
	Kwidzyn	0.8	0.0	2.0	230	22.0	14.0	30.0	32
	Male Walichnowy	2.9	2.0	5.0	37	3.2	2.0	5.0	40
	Wielkie Walichnowy	2.5	1.1	5.0	54	4.1	1.0	11.0	75

Water turbidity was also within safe levels in Tczew (0.4 NTU) and Kwidzyn (0.8 NTU). In the remaining distribution networks, average turbidity parameters exceeded the allowable norm. In many sites, the flow of water via the network had a negative effect on water quality, as shown by an increase in the turbidity of mains water samples in comparison with the samples collected from treatment stations in Dzierzgon, Sztum, Starogard Gdanski and Wielkie Walichnowy (Table 6).

The increase in turbidity parameters resulting from pipeline flow ranged from 14 % in Dzierzgon to 224 % in Starogard Gdanski. Although the turbidity of water samples collected in Kwidzyn was within the norm (0.8 NTU), the turbidity of water supplied to the end-user increased by 300 % on average, in comparison with water samples obtained from the treatment station (0.2 NTU).

An analysis of water supplied to end-users indicate that iron concentrations were also elevated in selected monitoring points. In comparison with the average iron content of water samples collected from treatment stations, the highest increase of 350 % was noted in the water mains in Gardeja, followed by Malbork (110 %), Sztum (78 %) and Tczew (50 %). In Tczew, the maximum allowable concentrations of iron were not exceeded despite the above increase. The iron content of water supplied to end-users decreased only in ZWM and Dzierzgon (Table 7).

Table 7

Statistical characteristics of iron and manganese concentrations in mains water samples collected in the Ilawa Lakeland, Starogard Lakeland, Zulawy and the Lower Vistula Valley in 1990–2004

Mesoregion	Intake	Iron [mg total Fe · dm^{-3}]				Manganese [mgMn · dm^{-3}]			
		Mean	Min	Max	*cv* [%]	Mean	Min	Max	*cv* [%]
Ilawa lakeland	Dzierzgon	0.33	0.20	0.50	30	0.079	0.030	0.100	28
	Sztum	0.32	0.02	0.40	8	0.093	0.040	0.160	14
Starogard Lakeland	Starogard Gdanski	0.50	0.20	1.14	60	0.073	0.030	0.100	60
	Tczew	0.15	0.02	0.20	47	0.002	0.000	0.010	108
	Tczewskie Laki	0.31	0.22	0.52	32	0.005	0.000	0.030	220
Vistula Zulawy	Malbork	0.21	0.08	0.30	71	0.020	0.000	0.040	100
	Zulawy Water Mains	0.16	0.01	0.60	56	0.130	0.020	0.400	100
Lower Vistula valley	Gardeja	0.45	0.03	0.75	157	0.145	0.050	0.430	142
	Gniew	0.29	0.10	0.40	58	0.034	0.031	0.055	130
	Kwidzyn	0.42	0.10	1.70	88	0.110	0.050	0.180	200
	Male Walichnowy	0.25	0.10	0.90	52	0.001	0.000	0.002	0
	Wielkie Walichnowy	0.25	0.10	0.45	42	0.002	0.000	0.006	0

Mains distribution had a varied effect on changes in the manganese content of water. The greatest variations were noted in sites with elevated manganese concentrations in raw and treated water, excluding the Zulawy Water Mains where the allowable concentrations of manganese were exceeded in all water types. Unexpected results were reported in Dzierzgon where manganese levels increased more than five-fold from 0.015 mgMn · dm^{-3} in treated water samples to 0.079 mgMn · dm^{-3} in mains water (Table 7). A lower, yet statistically significant increase was also observed in mains water in Kwidzyn (89 %). The above could be attributed to the condition of the distribution network – despite the significant impact of pipeline material (r = 0.24), the material applied in Dzierzgon and Kwidzyn networks was similar to that used in other monitoring sites (Table 1).

The color of mains water did not differ significantly from that reported in treated water samples. Despite the above, a significant correlation was noted between color and pipeline material (r = 0.21). This trend is illustrated in Table 5.

The results of analyses carried out between 1990 and 2004 point to significant correlations between the studied parameters affecting water quality in the distribution network. Such correlations were noted between water turbidity and iron content, as well as between water color and iron content (Fig. 2).

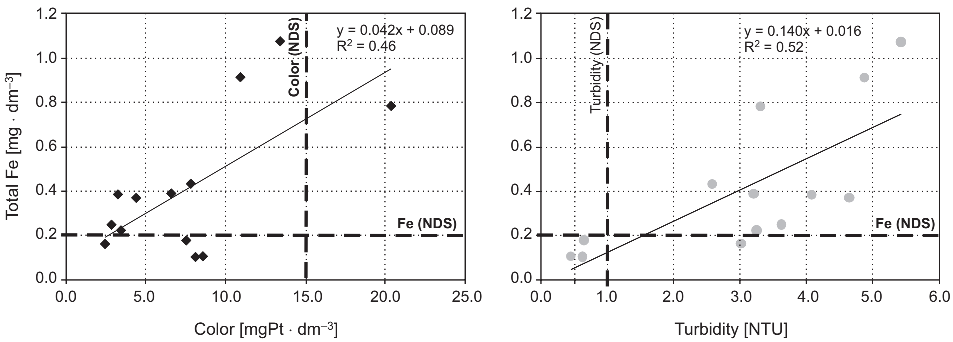

Fig. 2. Correlations between the iron content [mgFe · dm^{-3}] of mains water in the Ilawa Lakeland, Starogard Lakeland, Vistula Zulawy and the Lower Vistula Valley in 1990–2004, water color and turbidity

The flow of water through the distribution network modifies the parameters of treated water to a varied degree. This is an adverse phenomenon, as the final product supplied to end-users may not comply with standard requirements. For this reason, optical parameters and the manganese and iron content of potable water have to be monitored on a regular basis.

Conclusions

1. The optical properties of underground water samples intended for consumption (raw water) and water distributed via the mains network varied significantly due to the presence of iron and manganese.

2. The lowest quality parameters (high total iron and manganese concentrations) were noted in water samples from Quaternary deposits which had a 33 % share of all samples analyzed in the study. The highest iron concentrations were reported in raw water samples from Sztum (2.50–6.90 mg · dm^{-3}), followed by Gardeja (2.90–4.90 mg · dm^{-3}), Zulawy Water Mains (3.27–6.23 mg · dm^{-3}) and Starogard Gdanski (1.75–2.40 mg · dm^{-3}). Excessive manganese levels were observed in raw water samples from Zulawy Water Mains (0.72–1.72 mg · dm^{-3}), Sztum (0.19–0.40 mg · dm^{-3}), Gardeja (0.20–0.40 mg · dm^{-3}) and Starogard Gdanski (0.15–0.20 mg · dm^{-3}).

3. Elevated values of physical and chemical parameters indicate that raw water samples are not fit for direct consumption and require treatment. The average indicator of treatment effectiveness, expressed as the percentage of samples in which MAC

values for a given parameter were exceeded, was 29 % for iron and 22 % for manganese. The percentage of mains water samples in which MAC values were exceeded reached 56 % for iron and 34 % for manganese.

4. The introduction of more stringent treatment criteria led to an improvement in water quality. The turbidity, color, iron and manganese content of treated water was lowered. Yet standard parameters were exceeded in 70 % of the studied sites, indicating that the applied treatment methods are inefficient. Iron (60 %), manganese (40 %) and turbidity (60 %) levels were most significantly exceeded in water samples from the region of the Lower Vistula Valley.

5. Technological factors had a more significant impact on the analyzed parameters of treated and mains water than environmental factors. Although technological processes had a decisive effect on the quality of water supplied to end-users, the majority of the analyzed parameters were correlated with the origin of raw water samples.

6. The results of the study indicate that the mains network in Tczew which supplies the largest population (65,000) was characterized by the most satisfactory hydrogeological conditions, the highest treatment efficiency and the most satisfactory parameters of water supplied to end-users.

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CZYNNIKI WARUNKUJĄCE WŁAŚCIWOŚCI OPTYCZNE WÓD PODZIEMNYCH PRZEZNACZONYCH DO SPOŻYCIA

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Abstrakt: W oparciu o wyniki badań wód podziemnych, przeprowadzonych w latach 1990–2004, określono właściwości optyczne wód (barwa i mętność) oraz stężenie w nich związków żelaza i manganu. Wody pobierano z 12 punktów monitoringowych na ujęciach położonych w regionach: Dolina Dolnej Wisły, Żuławy Wiślane, Pojezierze Starogardzkie i Pojezierze Iławskie. Stwierdzono, że pod względem mętności badane wody surowe nie spełniały obowiązującej normy (1 NTU) i wymagały uzdatniania. O właściwościach optycznych ujmowanych wód decydowały stężenia w nich związków żelaza i manganu. W każdym z regionów występowały również wody zawierające duże ilości żelaza. Zdecydowanie najzasobniejsze w żelazo były wody surowe w ujęciu Sztum (od 2,50 do 6,90 $mgFe_{og.} \cdot dm^{-3}$), a najuboższe w Malborku (od 0,05 do 0,20 $mgFe_{og.} \cdot dm^{-3}$). Zaś największe stężenia manganu (0,72 do 1,72 $mg \cdot dm^{-3}$) stwierdzano w wodach surowych Centralnego Wodociągu Żuławskiego. Z kolei w Sztumie wynosiły one od 0,19 do 0,40 $mgMn \cdot dm^{-3}$, a w Kwidzynie od 0,14 do 0,30 $mgMn \cdot dm^{-3}$. Najmniejsze stężenia manganu występowały w wodach surowych, ujmowanych z pięter wodonośnych Trzeciorzędu i Kredy. Z tego względu wody te nie wymagały uzdatniania.

Kontakt wody z siecią na ogół zmieniał parametry wody uzdatnionej. Nie jest to zjawisko korzystne, bowiem odbiorca może otrzymać produkt niespełniający wymaganych norm. Dlatego tak ważne jest monitorowanie właściwości optycznych wody oraz zawartości w niej żelaza i manganu począwszy od ujęcia, poprzez stację uzdatniania do odbiorcy.

Słowa kluczowe: barwa, mętność, żelazo, mangan, piętra wodonośne, jakość wody