Pol. J. Environ. Stud. Vol. 22, No. 1 (2013), 159-165

Original Research

Quality Categories of Stream Waters Included in a Small Retention Program

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Received: 2 July 2012
Accepted: 15 October 2012

Abstract

Hydrochemcial research conducted from January 2007 to December 2010, and microbiological analyses performed from January 2007 to December 2009 included 12 streams in three areas of Małopolska Province, in which construction of small water reservoirs has been planned. Water samples were collected from the streams in measurement-control points situated on the sites of planned dams. Stream water suitability for domestic water supply was determined on the basis of 22 indices, including 20 physicochemical and two microbiological ones. In regards to regulations, it was concluded that water in 10 analyzed streams fulfilled the requirements for domestic water supply. Waters in all analyzed streams in the vicinity of Jordanów were classified as category A2 – requiring standard physical and chemical treatment. Waters in the streams in the area of Ryglice reveal a lower usability for domestic water supply because of their metal concentrations (manganese – A3 category, iron – A2 category) and microbiological indices (A2 category). In the Kraków neighborhood, waters of the Wilga and Szczyrzawa streams are in the same category due to the same indices as waters from the Ryglice area. The Sudół and Sudół Dominikański streams that flow through the suburban Kraków area carry strongly polluted waters that cannot be used for potable domestic water supply.

Keywords: water quality, stream, small retention

Introduction

In 1980-2010 the annual resources of surface water in Poland were about 1,6000 m^3 per inhabitant, which at an average estimated at 4,6000 m^3 in European countries causes Poland to be counted among countries with poor water resources. At the same time, water storage capacity of retention reservoirs in Poland is small and constitutes only 6% of the annual surface water runoff [1]. In order to solve these problems, Hydroproject Enterprise developed a Small Retention Program for Malopołska Province [2] which assumes construction of 65 small water storage reservoirs. In order to win a general approval of both specialists and, especially, local communities, planned reservoirs should fulfil various functions, among which the most important are the use of stored water for potable water supply to households and for other economic objectives, for recreation and rest, but also as natural fish habitat. The reservoirs should also improve landscape amenities and enrich environmental biodiversity [3]. Considering the fact that over 66% of potable water for Malopołska province inhabitants is abstracted from surface water intakes [4], the potential use of the small retention program [2] for storing quality water should be determined. In future the reservoirs may be water resources used by local communities at low treatment costs. This is in compliance with the EU-Framework Water Directive adopted in 2000 by EU member states, whose main objective is proper management and protection of water resources [5]. Council Directive 75/440/EEC [6], concerning the required quality of surface waters for

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potable water abstraction in the EU member countries, states 46 indices that determine water suitability for drinking. Surface waters, whose physical, chemical and microbiological properties do not fulfil the standard admissible values of A3 category treatment, cannot be used for abstraction of drinking water. Detailed provisions are stated by Council Directive 98/83/EC [7] on the quality of water designed for human consumption, which precisely determines the standards and adjusts them to more modern technologies to protect human health against negative effects of polluted water.

A worsening state of water quality drives increasingly more intensive research, leading to understanding the phenomena in aquatic environments and associated hydrological features. Chemical composition of water is a function of hydrogeochemical processes occurring in a catchment area [8-10]. There are numerous factors, such as climate, tectonics, topography and lythology, use, etc., that individually or combined affect the concentration and washing out of dissolved ions [9, 11-16].

Our paper aims to determine the quality category of stream waters included in the small retention program in three areas of Małopolska in view of their use for public supplies of water intended for consumption. The assessment was made on the basis of four-year investigations of select physical, oxygen, biogenic and microbiological indices, salinity, and metal concentrations.

Scope of Research and Methods

Hydrochemical research conducted from January 2007 to December 2010 and microbiological analyses from January 2007 to December 2009 covered 12 streams, on which construction of small water reservoirs was planned [2]. The analyzed streams are situated in three parts of the province, four near Jordanów (1) in Suski County, near Tarnów and Ryglice (2) in Tarnowski County, and Kraków (3) in Krakowski and Wielicki counties (Fig. 1). Catchment areas of the analyzed streams to the planned dam sites are from 3.25 (Bąbola) to 22.93 km^2 (Wilga). The reservoir of the smallest storage capacity (58.1 thousand m^3) will be built on Mostowy Potok, and the largest capacity (928.7 thousand m^3) on Korzeń Stream (Table 1) [17].

Water was sampled from the streams in measurement-control points situated on the sites of planned dams. 22

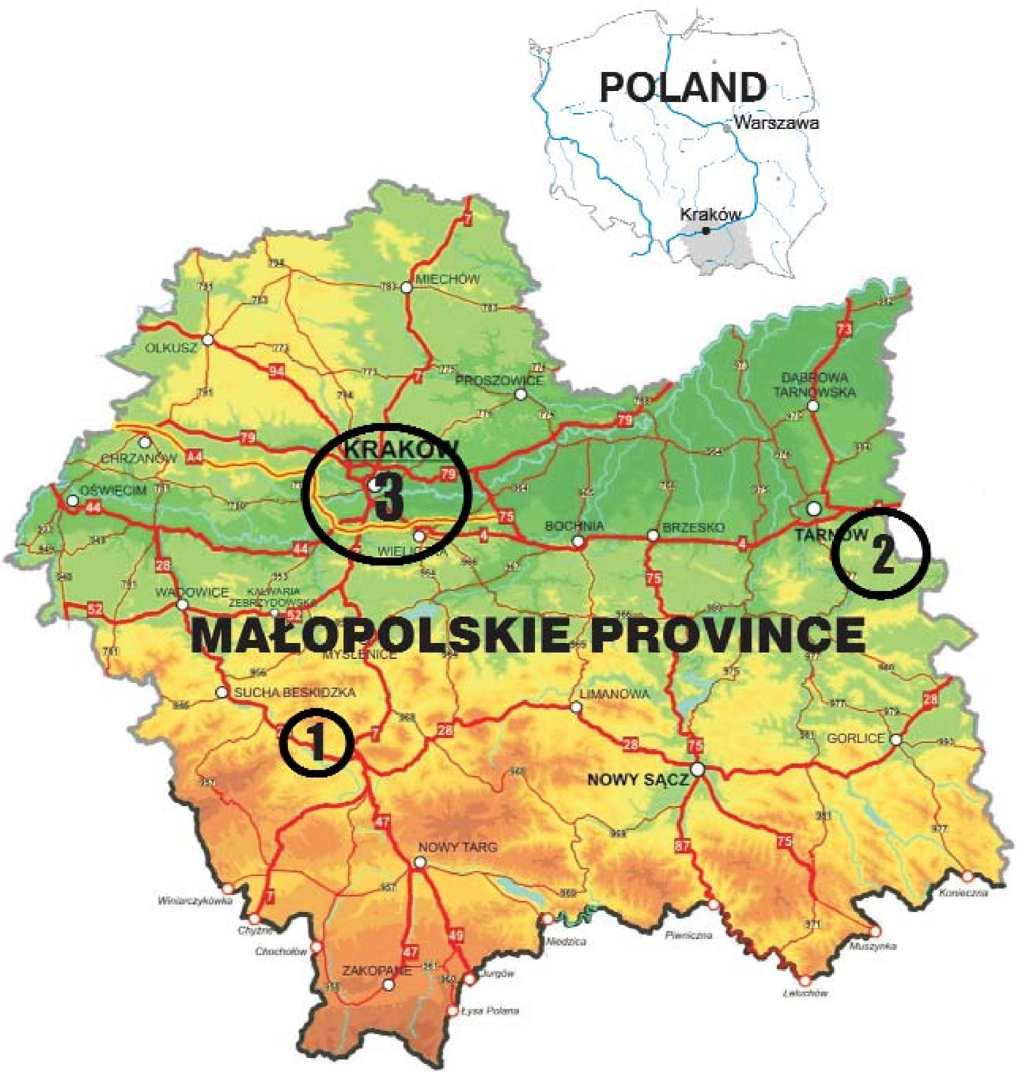

Fig. 1. Location of areas covered by research.

Table 1. Characteristics of analyzed catchments and capacity (V) of planned small retention reservoirs.

Stream name	Catchment area [km^2]	Type of land use	Range of altitudes [m a.s.l.]	Average land slope [%]	V [thous. m^3]
Głaza	8.94	Forest-agriculture + low density development	515-787	18.0	138.6
Mostowy Potok	6.35	Forest-agriculture + low density development	493-1018	21.2	58.1
Bąbola	3.25	Forest-agriculture	528-841	22.5	210.0
Osielczyk	4.92	Forest-agriculture	427-810	22.2	102.0
Korzeń	9.65	Forest-agriculture + scattered development	231-397	10.9	982.7
Wolninka	7.10	Forest-agriculture + scattered development	255-376	14.7	473.5
Rygliczanka	7.21	Forest-agriculture + scattered development	236-358	15.4	337.0
Potok Uniszowski	5.07	Forest-agriculture + low density development	234-534	17.5	467.0
Sudoł	14.69	Settlement-agriculture	221-373	4.1	73.2
Sudoł Dominikański	6.69	Agriculture-settlement	235-320	7.1	203.5
Wilga	22.93	Settlement-forest-agriculture	263-426	11.1	258.2
Szczyrzawy	6.26	Settlement-agriculture	210-277	4.2	515.0

indices were assessed, including 20 physicochemical and 2 microbiological ones. On site, water pH was measured with a CP-104 pehameter, electrolytic conductivity (EC) by CC-102 conductometer, and temperature and oxygen saturation by means of a CO-411 oxygen meter. In laboratory the following assessments were conducted using referential methods: concentrations of total suspended solids by gravimetric method, manganese ions (Mn^{2+}) and iron ions ($Fe^{2+/3+}$), chromium (Cr), zinc (Zn), cadmium (Cd), copper (Cu), nickel (Ni), and lead (Pb) by absorption atomic spectrometry on UNICAM SOLAR 969 spectrometer, concentrations of ammonium ion (NH_4^+), nitrates (NO_3^-), phosphates (PO_4^{3-}) and chlorides (Cl^-) by colorimetric analysis on an FIAstar 5000 Flow Injector Analyzer, sulphate concentration (SO_4^{2-}) by precipitation method, five-day biochemical oxygen demand (BOD_5) by Winkler's Method and chemical oxygen demand by permanganate method. Coliform bacteria and faecal coliform bacteria count were assessed on media with lactose, after incubation at 37 and 44ºC, with tolerance 0.5ºC. Most indices were assessed once a month. A total of 48 water samples were collected from each stream. Concentrations of chromium, zinc, cadmium, copper, nickel, and lead (16 dates), and coliform bacteria count (12 dates) were determined once every three months. All analyses were carried out in triplicate (relative standard deviation < 5%).

Stream water usability for public water supplies was assessed by comparing determined index values with permissible values as stated by the Ordinance of the Minister of the Natural Environment dated 27 November 2002 on the requirements for surface waters used for supplies of water intended for consumption [18], and the Ordinance of the Minister of Health of 29 March 2007 and 20 April 2010 on the quality of water intended for consumption [19, 20], which are in line with EU Directives [6, 7].

Results and Discussion

Hydrochemical analyses conducted in 2007-10 revealed that water flowing in the water courses are unsuitable for direct consumption by people due to the presence of bacteria from coli groups [7, 19, 21], and high concentrations of iron and manganese [7, 19]. Before the waters may be used for consumption, they must be subjected to standard treatment processes appropriate for respective water quality categories [18].

Stream water categories were determined for the whole four-year period of investigations. On the basis of 22 analyzed quality indices, it was found that water in streams flowing in the Jordanów neighborhood should be classified as category A2 (Table 2). In the case of Mostowy Potok and Osielczyk, it was determined by iron concentrations and microbiological index values. In four samples of water from Mostowy Potok and Osielczyk, iron concentrations exceeded the standard value 0.3 $mg \cdot dm^{-3}$, and the highest concentrations were, respectively, 0.84 and 0.94 $mg \cdot dm^{-3}$. Bacteria count exceeded the permissible norm on four and three dates, respectively, in water from Mostowy Potok and Osielczyk, where also the highest bacteria count was noted among all analyzed streams in this province (800 bacteria from coliform group and 400 bacteria of faecal coliform group per 100 ml of water). The other indices were within category A1, besides single values of phosphate concentration (1.09 $mg \cdot dm^{-3}$) and manganese (0.26 $mg \cdot dm^{-3}$) in Mostowy Potok water, deviating by 50% from the value permissible for category A1. Water in Głaza Stream was classified as A2 due to iron concentration, microbiological index values, and elevated water pH. In six samples from Głaza Stream water pH value was slightly higher than 8.5; the maximum measured pH value (8.63) was the highest in this province. However, in compliance with the Ordinance of the

Table 2. Water quality categories in analyzed streams determined on the basis of its suitability for supply people.

Groups of indices	Water quality index	Unit	Permissible values					Province, stream, and water quality category											
			Ordinance MH 2007 [19] CD 98/83/EC [7]	WHO [21]	Ordinance ME 2002 [18]			Jordanów				Tarnów				Kraków			
					Water quality category			Głaza	Mostowy Potok	Bąbola	Osielczyk	Korzeń	Wolninka	Rygliczanka	Potok Uniszowski	Sudół	Sudół Dominikański	Wilga	Szczyrzawy
					A1	A2	A3												
Physical	Temperature	ºC	–	–	25[1]	25[1]	25[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
	Total suspended solids	mg·dm^{-3}	–	–	25[2]	30[2]	35[2]	A1	A1	A1	A1	A1	A1	A1	A1	A2*	N	A1*	A1
	pH	–	6.5-9.5	6.5-9.5	6.5-8.5[2]	5.5-9.0[2]	5.5-9.0[2]	A2	A1	A2	A1	A1	A1	A1	A1	A1	A1	A1	A1
Oxygen	Water oxygen saturation	%	–	–	>70[2]	>50[2]	>30[2]	A1	A1	A1	A1	A1	A1	A1	A1	N	N	A1	A1
	BOD_5	mg O_2·dm^{-3}	–	–	<3[2]	<5[2]	<7[2]	A1	A1	A1	A1	A1	A1	A1	A1	N	N	A1	A1
	COD-Mn		–	–	25[2]	30[2]	30[2]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
Biogenic	PO_4^{3-}	mg·dm^{-3}	–	–	0.4[2]	0.7[2]	0.7[2]	A1	A1*	A1	A1	A1	A1	A1	A1	N	N	A1	A1*
	NH_4^+		0.5	–	0.5[2]	1.5[1]	2.0[1]	A1	A1	A1	A1	A1	A1	A1	A1	N	N	A1	A1
	NO_3^-		50	50	50[1]	50[1]	50[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
Salinity	EC	µS·cm^{-1}	2,500	–	1000[2]	1000[2]	1000[2]	A1	A1	A1	A1	A1	A1	A1	A1	N	N	A1	A1
	SO_4^{2-}	mg·dm^{-3}	250	–	250[1]	250[1]	250[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
	Cl^-		250	–	250[2]	250[2]	250[2]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
Metals. incl. heavy metals	FeV		0.2	–	0.3[1]	2[1]	2[2]	A2	A2	A1	A2	A2	A2	A2	A2	A2	A2	A2	A2*
	Mn^{2+}		0.05	–	0.05[2]	0.1[2]	1[2]	A1	A1*	A1*	A1	A3	A3	A3	A3	A3	A3	A3	A3
	Cr		0.05	0.05	0.05[1]	0.05[1]	0.05[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1**	A1**	A1	A1
	Zn		–	–	3[1]	5[1]	5[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
	Cd		0.005	0.003	0.005[1]	0.005[1]	0.005[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
	Cu		2	2	0.05[1]	0.05[1]	0.5[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1**	A1	A1	A1
	Ni		0.02	0.07	0.05[2]	0.05[2]	0.2[2]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
	Pb		0.025	0.01	0.05[1]	0.05[1]	0.05[1]	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1	A1
Microbio-logical	FCB	per 100 ml of water	–	–	20[2]	2000[2]	20000[2]	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2
	CB		0	0	50[2]	5000[2]	50000[2]	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2

EC – electrolytic conductivity, FCB – faecal coliform bacteria count, CB – coliform bacteria count

[1] – for 95% of samples; [2] – for 90% of samples; N – values of the index do not meet the requirements for water intended for public supplies of water, *– index value deviates by 50% from the permissible value in one sample, ** – index value exceeds the permissible value in one sample. no exceeded values were noted in subsequent samples

Minister of Health [20], the admissible pH range in potable water is from 6.5 to 9.5 and is taken into consideration as an assessment of aggressive corroding properties of water. Iron concentrations in 12 water samples were higher than 0.3 $mg \cdot dm^{-3}$, but none exceeded 1 $mg \cdot dm^{-3}$. Coliform bacteria and faecal coliform bacteria count exceeded 50 and 20 bacteria per 100 ml of water, respectively, in 6 and 7 collected samples. Their maximum count was 400 of coliform group and 300 of faecal coliform group. Water from Bąbola Stream was classified as A2 due to its pH and microbiological indices. In five samples from the Bąbola stream water pH slightly exceeded 8.5, whereas in three samples the permissible count of both bacteria groups were exceeded. In one water sample manganese concentration (0.47 $mg \cdot dm^{-3}$) deviated by 50% from the value permissible for A1 category; still, it did not affect water quality evaluation.

Stream waters in the neighborhood of Tarnów and Ryglice were classified to A3 category because of manganese concentrations. In water of the Rygliczka and Wolnika streams manganese concentrations above 0.1 $mg \cdot dm^{-3}$ was registered on 19 dates, whereas in the Korzeń and Potok Uniszowski streams on 18 dates. Maximum manganese values ranged from 0.25 $mg \cdot dm^{-3}$ (Korzeń) to 0.49 $mg \cdot dm^{-3}$ (Rygliczanka). These waters were classified to A2 category due to iron concentrations, whose value ranged from 0.3 to 2 $mg \cdot dm^{-3}$ and registered in 58% of samples from the Korzeń stream, 67% from Potok Uniszowski, 73% from Rygliczanka, and in 81% of samples from the Wolninka stream. On one date iron concentration exceeded the value permissible for A2 category, i.e. 2.21 $mg \cdot dm^{-3}$ for the Korzeń stream and 2.52 $mg \cdot dm^{-3}$ for Rygliczanka. Values of microbiological indices were high and classified water in these streams to A2 category. Only two water samples from the Rygliczanka stream, three from Wolninka and five from the Potok Uniszowski stream were classified to A1 category. Exceeded values permissible for A1 category were noted in all water samples collected from the Korzeń stream. The highest coliform bacteria count in this province (1600 per 100 ml of water) and faecal coliform bacteria count (700 per 100 ml of water) was registered in the Rygliczanka stream water.

In the vicinity of Kraków, waters in the Wilga and Szczyrzawa streams were classified to the same category as stream waters in the area of Ryglice. These waters are classed to category A3 because of manganese concentrations. In water from the Wilga stream the value was exceeded on 7 dates (maximum value 0.17 $mg \cdot dm^{-3}$) in Szczyrzawa stream on 27 dates (maximum value 0.41 $mg \cdot dm^{-3}$). Because of iron concentrations these stream waters were classed to A2 category, since the value permissible for A1 category was exceeded respectively on 23 and 32 dates. On two dates iron concentrations in Szczyrzawa stream reached values beyond the norm, respectively 2.44 $mg \cdot dm^{-3}$ and 3.53 $mg \cdot dm^{-3}$ (the value deviated by 50% from the value admissible for A3 category). Because on subsequent dates no exceeded permissible values for iron concentrations were registered, water in Szczyrzawa stream was classified to category A2. Also, microbiological indices classified waters from these streams to category A2. Exceeded permissible values for category A1 were noted in 4 samples collected from the Wilga stream and in 5 water samples from Szczyrzawa Stream. Maximum coliform bacteria count in these streams was 860 and faecal coliform 600. Among the analyzed streams, water in the Sudół and Sudół Dominikański streams was the most polluted and did not meet the standard for A3 because of too low water saturation with oxygen, high values of BOD_5, electrolytic conductivity, concentrations of phosphates and ammonium ion, and additionally total suspended solids in Sudół Dominikański Stream. Values of oxygen and biogenic indices several times or in some cases even many times exceeded values permissible for A3. Higher-than-permissible values of some heavy metal concentrations were registered in water from these streams. At the beginning of investigations, a single exceeded permissible chromium concentration (0.06-0.71 $mg \cdot dm^{-3}$) was noted in three streams, and copper (0.068 $mg \cdot dm^{-3}$) in Sudół Stream. According to regulations, values of heavy metal concentrations (except nickel) must meet the standard for 95% of samples, which means that in each of the 16 samples, their values should be lower than or equal to the permissible values. Because in the final years of the investigations no exceeded normative values of heavy metal concentrations were registered, the water was classified to category A1.

Considerable pollution of water in the suburban Sudół and Sudół Dominikański streams make impossible their use for household purposes, resulting from high anthropopressure in the catchment area. Hydrochemical research conducted by Kanownik and Rajda [22, 23] demonstrated that water pollution in these streams was increasing with their course and was associated with immediate draining of rainwater from numerous roads with heavy traffic into these streams, as well as treated sewage discharge from small local treatment plants.

Obtained results are obviously correlated with studies conducted by the Voivodeship Inspectorate for Environmental Protection in Kraków above water intakes supplying on average over 100 m^3 of drinking water per day. The report on the state of the environment in Malopołska Province in 2010 [4], prepared on the basis of research conducted on 26 rivers in 33 measurement-control points and on 1 dam reservoir, shows that water in A1 category was noted only in one point, A2 category waters in 12 points, and A3 category waters in 18 points, whereas waters in 3 points did not meet the standard. As in the studied streams, the main cause of decreased water suitability for public water supplies were microbiological impurities (coliform bacteria count and faecal coliform bacteria count). Also, research conducted on the Dunajec river before water intake for Stary Sącz by Świniarsko [24] and by Aydin in western Turkey [10] demonstrated that water category is determined by microbiological indices.

The second group decreasing the quality of surface waters are metals, mainly manganese and iron, usually originating from natural sources. Their concentrations are usually connected with the geological structure of the catchment,

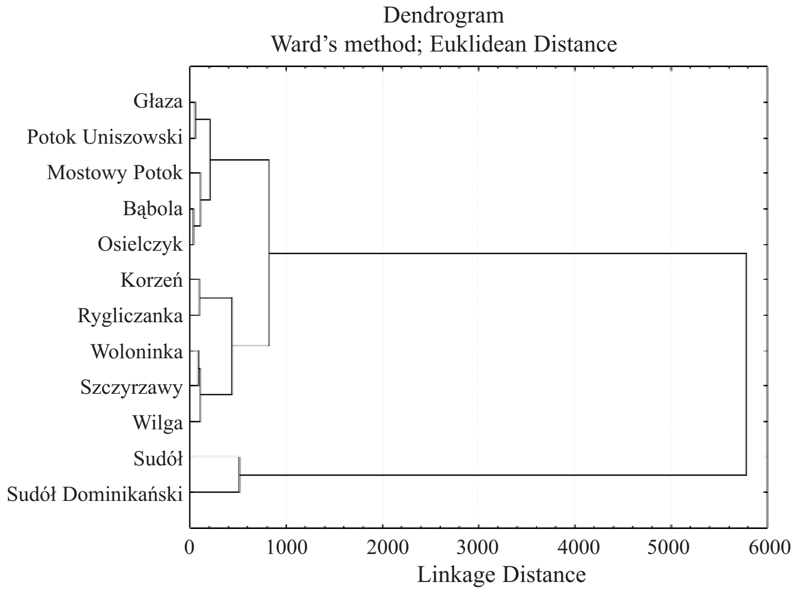

Fig. 2. Dendrogram (Ward's method) of the analyzed streams regarding selected biological and physicochemical characteristics of water.

chemical composition of rocks and soils in the catchment and riverbeds [11, 25, 26]. This fact was confirmed in the province of Trabzon, Turkey on Galman Stream [11], and also by long-term investigations conducted on the Wisłok river before potable water intake for Mielec. Research conducted in 1992-2010 on the Wisłok River revealed high concentrations of manganese and iron, which allowed to classifying water respectively to A3 and A2 categories. On the other hand, heavy metal concentrations (including copper, nickel, chromium, lead, and cadmium) were low, below the permissible range determined as the norms for water destined for potable water supply for people [26].

As a result of cluster analysis (agglomeration method), a hierarchy of clusters was obtained, presented as a dendrogram (Fig. 2). It allows us to make an objective assessment of the similarity, irrespective of the scales, in which individual features were expressed. Estimating the distances between clusters was made using Ward's method, which is based on the analysis of variance and aims to minimize the sum of squares of any two clusters. It results from the dendrogram that, due to a similarity of studied biological and physicochemical water properties, the streams are clustered in three groups. The streams Głaza, Potok Uniszowski, Mostowy Potok, Bąbola, and Osielczyk belong to the group of best water quality. Catchments of all above-mentioned streams are characterized by agricultural and forest land use type with low density development. The second group consists of streams with agricultural and forest type of land use in catchment with dispersed development, settlement, and agricultural land use, and settlement forestry and agricultural land use. The third group is composed of two streams the Sudół and Sudół Dominikański, located in suburban Kraków. Water in these streams is strongly polluted and is unsuitable for public supplies of water intended for consumption.

Conclusions

Considering the ministers' regulations, it was determined that water in 10 studied streams meets the requirement for public supplies of water intended for consumption. Waters in all studied streams in the province of Jordanów were classified to A2 category, in the case of Głaza stream due to 4 indices and in the other streams due to 3 indices. Water in the streams in Ryglice area reveal a decreased suitability for public supply of water intended for consumption because of metal concentrations (manganese – A3 category and iron A2 category) and microbiological indices – A2 category. Water in the Wilga and Szczyrzawa streams in the vicinity of Kraków are in the same category due to the same indices as waters from the Ryglice area.

Water from the streams in Jordanów province requires a typical physical and chemical treatment, i.e. initial oxidation, coagulation, flocculation, decantation, filtration, and disinfection, water in the area of Tarnów and Ryglice as well in the Wilga and Szczyrzawa province (near Kraków) requires highly efficient physical and chemical treatment. The necessity of this water treatment before consumption is caused by a high concentration of manganese and iron washed out from the catchment substratum and high coliform bacteria count resulting from uncontrolled sewage discharge from households and farms.

The Sudół and Sudół Dominikański streams in suburban Kraków carry strongly polluted waters (respectively, 5 and 6 water quality indices do not meet the requirements for A3). It is caused by considerable anthropogenic pressure: high population density in the catchment area, industrial pollution, inefficient sewage treatment plants, and low absorptivity of the watercourses. Water in these streams cannot be used for utilitarian purposes, including drinking water supply to households. Heavy pollutant load in the water would shortly lead to degradation of the planned reservoirs. Therefore, they should be made as dry reservoirs, i.e. fulfilling only the flood prevention function.

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