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Water treatment in a natural mountain catchment (Wapienica dam reservoir, southern Poland)

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ABSTRACT

The paper deals with water quality of Wapienica dam reservoir and the treatment of its water for consumption. The reservoir is located in a mountain catchment, where human activities are restricted to sustainable forest management. The reservoir was constructed between 1928 and 1932 as a reservoir of potable water for the city of Bielsko-Biala. In years 2011–2012, analyses of water quality were carried out for raw water in the reservoir and treated water which was pumped into the water supply network. The paper also shows Polish legal regulations which set conditions for the treatment of water and use of water for consumption. The research showed that water retained in the reservoir has good quality, and its treatment can only be based on filtration and disinfection. Only in conditions of excessive turbidity should a process of coagulation be used. Treated water meets the criteria which are set for potable water. It has low concentration of macroelements and trace elements. The research showed benefits coming from location of reservoirs in natural catchments, which are not managed by man. Water which is taken from such reservoirs does not need costly treatment processes.

Keywords: Mountain catchment; Dam reservoir; Quality of water; Water treatment; Water supply

1. Introduction

Reserves of fresh water which are available to the mankind (water in rivers and lakes, as well as part of underground water) account for as little as 0.4–1.0% of total water on the earth [1]. The volume of renewable resources which can be used is even smaller (0.10–0.15% of fresh water). Only regionally are water reserves high enough to avoid the need to retain water. In most countries, including Poland, growing settlement, agriculture and industry brought about the need to retain and store river water flowing into seas and oceans. Thus, rivers were cut with dams, creating retention reservoirs of sweet water. According to the data from the International Commission on Large Dams, there are at least 50,000 reservoirs [2] in the world, created as a result of building dams over 10 meters high. Reservoirs are used for many purposes [2], mainly for irrigation in agriculture (48.6% reservoirs), for hydroenergetics (17.4%), as supplies of potable and industrial water (12.7%) and as flood

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control reservoirs (10.0%) or for recreation (5.3%). Most issues concern the use of reservoir water for drinking, as most of surface water is polluted to some degree. River water flowing into reservoirs contains municipal [3], agricultural [4] or industrial contaminants [5]; most frequently, these are mixed contaminants coming from multiple sources [6,7]. Additionally, many reservoirs are exposed to eutrophication processes [8–10]. Such water needs purification before it is used for consumption. Depending on water parameters, purification consists in respective physical, chemical and biological processes—from simple and cheap ones (e.g. filtration) to complicated and costly ones (like membrane processes).

Contaminants mainly reach dam reservoirs through inflowing rivers and streams, and the quantity and kind of incoming substances depend on anthropogenic influences on the environment of the catchment [11]. Thus, it can be assumed that retaining good-quality water in reservoirs is possible if the environment of the catchment is not affected by municipal-economic pressure. The present article verifies the assumption by presenting the operation of a dam reservoir whose catchment is natural—it is almost completely covered by forest. This is reservoir Wapienica, situated in mountainous regions of southern Poland in the valley of the Wapienica stream (Fig. 1). Water from the reservoir is used for consumption by the city of Bielsko-Biala and nearby municipalities. The reservoir is situated about 8 km away from the city centre, outside the urbanized area. The aims of the research were as follows: (1) to assess the quality of water retained in Wapienica reservoir; (2) to determine conditions for these reserves of water to be used in the water supply system; and (3) to assess the effectiveness of water treatment.

Wapienica reservoir is currently administered and used by water supply and sewerage company AQUA S.A. The dam was built between 1928 and 1932, by damming the valley of the mountain stream Wapienica. Before that, water for the city had come from draining intakes in the Wapienica valley and numerous municipal wells. The coordinates for the dam are as follows: 49°46′22′′N and 18°51′22′′E. This is one of the oldest concrete dams in Europe. It is 24 m high and its top is 310 m long. When the reservoir is filled to the maximum (water table at the height of 477.6 m a.s.l.), its surface area is 17.5 ha with a capacity of

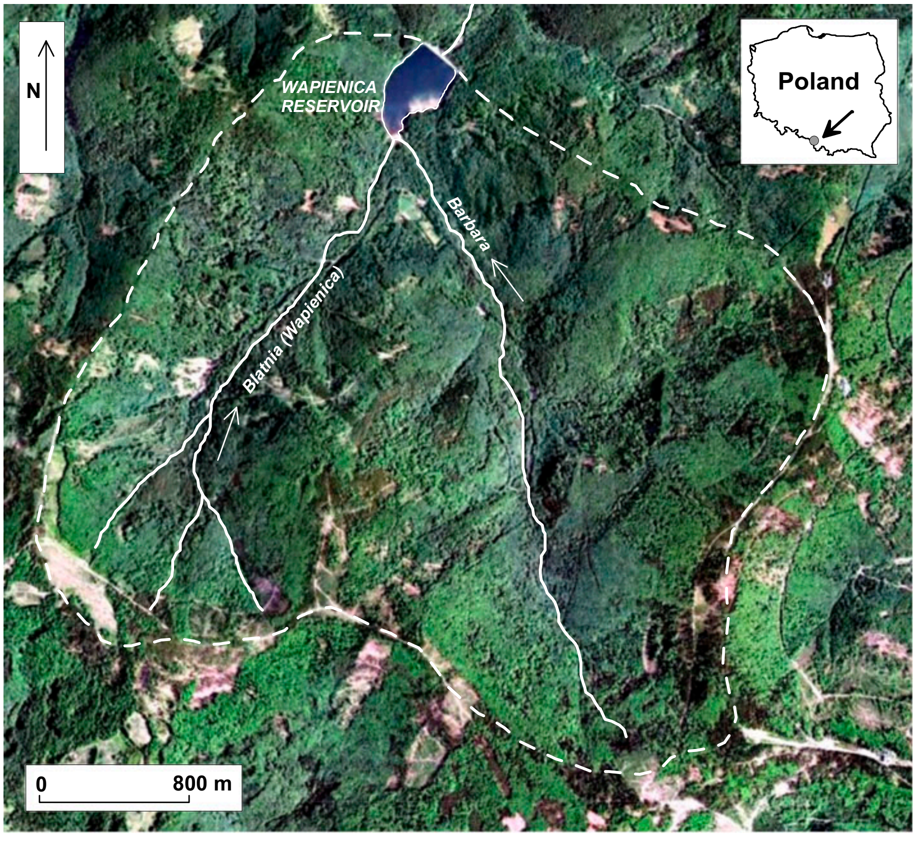

Fig. 1. The catchment of the Wapienica dam reservoir.

1.05 million m^3. The average depth of the reservoir is 8 m and maximum-20 m. By retaining water with the dam, the valley was flooded at the 600-meter-long section and the reservoir is about 300 m wide on average. Two mountain streams flow into the reservoir: the Blatnia (source stream for the Wapienica) and the Barbara (Fig. 1). They provide about 25,000 m^3 of water per day on average. Reservoir water is taken to the nearby treatment station at an average rate of 22,000 m^3 per day [12]. Water-taking devices are located on the wall of the dam, at 463–467 m a.s.l. That is why the water table in the reservoir cannot be lowered below 463 m a.s.l. After treatment, water flows gravitationally down to the water mains network which covers the city of Bielsko-Biala and neighbouring municipalities. Of course, Wapienica reservoir is not the only source of water for the water supply network.

2. Methods

The research started with the assessment of the area of the catchment of Wapienica reservoir, in order to confirm its natural origins. Assessment was made using a topographic map 1:10,000 as well as satellite imagery. Human activities in the area of the catchment were analysed based on available references on the subject matter (regarding forest management). The assessment was verified directly in the field research.

The main part of the research consisted of analyses of major qualitative parameters of water in the reservoir and treated water transferred to the water supply network. Water samples were taken within one year (between September 2011 and August 2012) and transported to the central laboratory of AQUA S.A., where physiochemical analyses were carried out. The laboratory is accredited by the Polish Center for Accreditation. Laboratory analyses were carried out according to ISO norms as well as Polish norms.

Water from the reservoir was taken for analyses four times (13 September 2011, 6 December 2011, 13 March 2012, 18 June 2012). Samples were taken in the near-dam zone, in the area of water intake. In Poland, water may be taken from rivers, reservoirs and lakes, and purified for consumption if it meets the criteria for 44 qualitative parameters set forth by the Minister of Environment [13]. That is why the results of physiochemical and biological analyses obtained for major parameters were compared against the values set in the legal regulations. According to these regulations, water may be qualified in category A1, A2 or A3. If it does not meet the criteria for any of these categories, it cannot be taken for treatment and also for consumption. Category A1 water is considered pure and it only needs simple physical treatment, especially filtration and disinfection. Water of poorer quality (category A2) needs wider physical and chemical treatment, especially pre-oxidation, coagulation, flocculation, decantation, filtration and disinfection by final chlorination. Water qualified in category A3 needs advanced physical and chemical treatment including processes of oxidation, coagulation, flocculation, decantation, filtration, adsorption with activated carbon, as well as disinfection by ozonation and final chlorination.

Treated water, coming to the water supply system, was taken for laboratory analyses every few days. According to Polish regulations, such water should meet the requirements for 28 primary and 35 secondary qualitative parameters [14]. Results obtained for major parameters were compared against required values.

3. Results and discussion

The catchment of reservoir Wapienica is a mountain catchment and it covers the area of 11.1 km^2. It is located in the western part of the Polish Carpathians. The catchment is cone-shaped and the divide runs through the following peaks: Szyndzielnia (1,028 m a.s.l.), Klimczok (1,117 m a.s.l.), Stolow (1,035 m a.s.l.) and Blatnia (917 m a.s.l.). The terrain of the catchment slopes down in the north and the water table in the reservoir is about 470 m a.s.l. Water flows from the catchment mainly through streams Blatnia and Barbara, which flow into the reservoir. The rest of the catchment, with area of 1.16 km^2, is not relevant for feeding of the reservoir. The bedrock of the catchment is built of fine sandstones and clay stone. Three types of soil occur there: podsolic soil, brown soil and alluvial soil.

The area of the catchment is almost completely covered with woods. The forest cover consists mainly of spruce woods, fir–spruce woods, acid Carpathian beech wood, fertile Carpathian beech wood and mountain sycamore wood. Small treeless areas are a result of forest being destroyed by wind. These areas are forested by the Bielsko Forest Inspectorate, which is the owner of the forests in the catchment. What proves little anthropogenic impact on the environment of the catchment is the following facts regarding human activities:

- all forest work is carried out according to the principles of sustainable forest management;
- there is only one household within the catchment—it is a forester's lodge;

- little-frequented walking–cycling route runs in the central part of the catchment and walking tourist routes run along the divide;
- it is forbidden to drive a private car within the catchment;
- the reservoir is not accessible for recreation (swimming and sunbathing).

Thus, it is justifiable to conclude that there are no significant sources of contamination in the catchment of the reservoir. A possible source of contamination of water in the catchment might be the atmosphere, as deposition of atmospheric substances concerns even areas which are located far from emitters [15,16]. Contaminants that might enter the area of the catchment might be those from nearby industrial regions: Upper Silesian in Poland and Ostravian in the Czech Republic.

Analyses of parameters of water in the reservoir showed its good quality (Table 1). Water was not contaminated with organic substances, which was confirmed by low values of BOD_5 (2.4 mg O_2 dm^{-3} maximum) and COD_{Cr} (below 10 mg O_2 dm^{-3}). High concentration of dissolved oxygen (between 8.8 and 12.1 mg O_2 dm^{-3}) might be considered a factor which favours decomposition of organic substances. Reservoir water also contained low amounts of dissolved mineral substances. This was confirmed by low values of electric conductivity, which were at a few dozen μS cm^{-1}, and maximally 186 μS cm^{-1} (the amount of dissolved substances in that sample was only 117 mg dm^{-3}). Low concentrations were reported for chlorides (below 5 mg Cl^- dm^{-3}) and sulphates (maximum 20.5 mg SO_4^{2-} dm^{-3}), as well as biogenic compounds of nitrogen and phosphorus. Nitrates(V) were reported between 2.6 and 5.0 mg NO_3^- dm^{-3}, and phosphates occurred at 0.09 mg PO_4^{3-} dm^{-3} maximum. No signs of eutrophication of the reservoir were observed during the research. Low fertility of water was earlier reported by Jachniak and Kozak [17], who carried out phytoplankton research. They determined the concentration of biomass in water at an average level of 0.7 mg dm^{-3} and identified species typical of oligotrophic water. Concentrations of microcontaminants in the reservoir water were generally safe for water ecosystems [18]. For example, maximum concentration of zinc was 28 μg dm^{-3}, while that metal becomes toxic for fish when its concentration exceeds 100 μg dm^{-3}. Cobalt occurred maximally at 10 μg dm 3, and the threat occurs in case of concentrations exceeding a few dozen mg dm^{-3}. In case of lead, the concentration of 5 μg dm^{-3}, which is regarded as a threshold for safety of water biocenoses, was only reported to be exceeded once. Chrome and nickel occurred in very small amounts.

Based on the physiochemical analyses, water in Wapienica reservoir can be classified as category A1 (Table 1). Microbiological analyses were also carried out. No *salmonella bacteria* were found in the samples, and *enterococci* were only reported once at 12 organisms per 100 cm^3 of water. These results also qualify water in category A1. Only the number of coliform bacteria exceeded the allowed amount for category A1, i.e. 50 cells per 100 cm^3 of water. Occurrence of these bacteria, at up to 240 cells, was within the criteria for category A2. Results of the research showed that raw water from the reservoir has good quality, but it cannot be transferred to the water mains without treatment. According to the law [14], not all analysed parameters met the requirements for potable water. These included turbidity, concentrations of aluminum and lead (metals in the reservoir water possibly come from atmospheric deposition), and occurrence of enterococci and coliform bacteria.

Water from Wapienica reservoir is subject to treatment in the treatment station situated below the dam. Raw water flows through the dam in two pipes, 300 mm in diameter each. Nephelometric measurement of turbidity is carried out in one of the pipes. If turbidity exceeds 25 NTU, which happens rarely, coagulant with trade name PAX-18 is applied in the pipes. It is polyaluminum chloride water solution with the following chemical composition: Al_2O_3—17, Al^{3+}—9, Cl^-—21 and Fe^{3+}—0.6%. Coagulation is used in order to remove colloids and fine suspended matter from water and deposit some compounds (e.g. phosphates). Water leaves the dam (without or with coagulant) through a 500 mm pipe to the treatment station. First, it reaches distribution channels. These channels distribute water to 12 filtration chambers. Each chamber has an anthracite-sand filter. Its upper part is an 0.6-m-thick layer anthracite, grain size 0.8–2.0 mm, and the lower part, also 0.6-metre-thick, is made of silica sand, grain size 0.6–0.8 mm. The efficiency of the filtration station is 45,000 m^3 per day at turbidity 0–20 NTU, and 25,000 m^3 per day at turbidity 20–100 NTU. After filtration, water is drained to a reservoir of clean water. The structure of the draining system makes it impossible for filtrated matter to leave the filters. Filters are regularly cleaned using washing pumps and blowers. From the reservoir, water flows gravitationally to the water mains. Water is disinfected in draining pipes using sodium hypochlorite which is produced from salt in the treatment station. Water solution of sodium hypochlorite (0.6% solution) is dosed by three pumps with capacities between 54 and 210 L per h. Up to 50,000 m^3 of water can be disinfected per day. This information shows that the treatment technology for water from reservoir Wapienica is

Table 1
Quality of Wapienica reservoir raw water according to the requirements for water treatment for consumption

Parameter	Wapienica reservoir water Value range	Water category for treatment [13] A1	A2	A3	Wapienica reservoir water Category
Reaction (pH)	6.9–7.7	6.5–8.5	5.5–9.0	5.5–9.0	A1
Suspension ($mg\,dm^{-3}$)	<5	<25	<30	<35	A1
Turbidity (NTU)	0.83–3.60	No restrictions			–
Dissolved oxygen ($mg\,O_2\,dm^{-3}$)	8.8–12.1	No restrictions			–
BOD_5 ($mg\,O_2\,dm-^{3}$)	Upto 2.4	<3	<5	<7	A1
COD_{Mn} ($mg\,O_2\,dm^{-3}$)	1.14–2.12	No restrictions			–
COD_{Cr} ($mg\,O_2\,dm^{-3}$)	<10	<25	<30	<30	A1
Conductivity ($\mu S\,cm^{-1}$)	68–186	<1,000	<1,000	<1,000	A1
Calcium ($mg\,Ca\,dm^{-3}$)	8.8–25.9	No restrictions			–
Magnesium ($mg\,Mg\,dm^{-3}$)	1.26–4.42	No restrictions			–
Chlorides ($mg\,Cl^{-}\,dm^{-3}$)	<5	<250	<250	<250	A1
Fluorides ($mg\,F^{-}\,dm^{-3}$)	0.07–0.28	<1.5	<1.5	<1.5	A1
Sulphates ($mg\,SO_4^{2-}$)	7.2–20.5	<250	<250	<250	A1
Ammonia ($mg\,NH_4^{+}\,dm^{-3}$)	<0.1	<0.5	<1.5	<2.0	A1
Nitrates(III) ($mg\,NO_2^{-}\,dm^{-3}$)	0.002–0.011	No restrictions			–
Nitrates(V) ($mg\,NO_3^{-}\,dm^{-3}$)	2.6–5.0	<50	<50	<50	A1
Phosphates ($mg\,PO_4^{3-}\,dm^{-3}$)	Upto 0.09	<0.4	<0.7	<0.7	A1
Manganese ($mg\,Mn\,dm^{-3}$)	Upto 0.018	<0.05	<0.1	<1	A1
Aluminium ($mg\,Al\,dm^{-3}$)	Upto 0.486	No restrictions			–
Barium ($mg\,Ba\,dm^{-3}$)	0.015–0.036	<0.1	<1	<1	A1
Boron ($mg\,B\,dm^{-3}$)	<0.1	<1	<1	<1	A1
Iron total $mg\,Fe\,dm^{-3}$)	0.086–0.170	<0.3	<2	<2	A1
Selenium ($mg\,Se\,dm^{-3}$)	<0.01	<0.01	<0.01	<0.01	A1
Zinc ($\mu g\,Zn\,dm^{-3}$)	Upto 28	<3,000	<5,000	<5,000	A1
Copper ($\mu g\,Cu\,dm^{-3}$)	<20	<50	<50	<500	A1
Chromium ($\mu g\,Cr\,dm^{-3}$)	Upto 6	<50	<50	<50	A1
Nickel ($\mu g\,Ni\,dm^{-3}$)	<2	<50	<50	<200	A1
Lead ($\mu g\,Pb\,dm^{-3}$)	Upto 11	<50	<50	<50	A1
Cadmium ($\mu g\,Cd\,dm^{-3}$)	<1	<5	<5	<5	A1
Cobalt ($\mu g\,Co\,dm^{-3}$)	Upto 10	No restrictions			–

adjusted for good-quality water. Treatment consists of filtration and disinfection, which is recommended for water classified in category A1. Filtration mainly ensures removal of suspended matter along with absorbed microcontaminants, while disinfection provides microbiological safety.

Very favourable values of qualitative parameters of treated water were obtained in laboratory analyses (Table 2). Water contained small amounts of primary substances and microelements. Dangerous heavy metals like chrome, cadmium, nickel and lead only occurred in concentrations a few $\mu g\,dm^{-3}$ at most. Nitrates(III), which are regarded to be carcinogenic, also occurred in trace amounts. Values of some of the parameters were slightly reduced in the treatment process. Within the research, this concerned electric conductivity, as well as concentrations of calcium, magnesium, sulphates and aluminium. Values of all determined parameters of treated water were within the requirements for potable water in water mains (Table 2). The administrator of the water mains AQUA S.A. guarantees that all quality requirements for treated water from Wapienica reservoir are met. That also applies to microbiological requirements, according to which water must not contain *coliform* bacteria (especially *Escherichia coli*), enterococci or *Clostridium perfringens*. It is worth adding that quality requirements regarding potable water differ between countries. They are often modified, mainly by introducing new parameters and lowering allowed concentrations of particular substances. Attempts are also made to standardize the quality requirements for potable water in the world [19]. Goncharuk [20] claims that changes in determining the parameters for potable water are necessary, because its quality is more and more under threat. That results, among other factors, from the fact that many microcontaminants are identified in water, which were not found in the water environment before. Researchers from different countries report problems with quality of potable water, because even after treatment, it still does not meet all quality requirements [21,22].

The research showed that treatment of water from the Wapienica reservoir for consumption can only consist of filtration and disinfection. It is a unique situation throughout Poland. Usually, more processes are used during the treatment of surface water, which increases the production cost of potable water. Consumers of treated water from that reservoir can be sure that it is safe for their health,which results from the clean environment of the catchment of the reservoir. In order to prevent the quality of water from deteriorating, the area of the catchment must remain free from human economic activities. Only in such conditions will the current treatment technology be sufficient.

Table 2
Quality of Wapienica reservoir treated water (based on data from AQUA S.A.) according to the requirements for drinking water

	Wapienica reservoir treated water			
Parameter	Number of samples	Value range	Mean value	Requirements for drinking water [14]
Reaction (pH)	161	6.7–7.4	7.07	6.5–9.5
Conductivity ($\mu S\,cm^{-1}$)	161	66.9–153.4	87.39	<2500.0
Nitrates(III) ($mg\,NO_2^-\,dm^{-3}$)	12	0.002–0.002	0.002	<0.1
Nitrates(V) ($mg\,NO_3^-\,dm^{-3}$)	161	3.0–6.0	3.75	<50.0
Chlorides ($mg\,Cl^-\,dm^{-3}$)	12	5.0–5.4	5.04	<250.0
Fluorides ($mg\,F^-\,dm^{-3}$)	12	0.06–0.24	0.14	<1.5
Sulphates ($mg\,SO_4^{2-}\,dm^{-3}$)	12	7.0–10.1	8.34	<250
Calcium ($mg\,Ca\,dm^{-3}$)	12	7.6–13.0	9.71	No restrictions
Magnesium ($mg\,Mg\,dm^{-3}$)	12	1.04–1.72	1.38	<125.0
Iron total ($mg\,Fe\,dm^{-3}$)	151	0.020–0.199	0.07	<0.2
Phosphorus total ($mg\,P\,dm^{-3}$)	13	0.004–1.782	0.207	No restrictions
Manganese ($mg\,Mn\,dm^{-3}$)	44	0.020–0.039	0.023	<0.05
Chromium ($mg\,Cr\,dm^{-3}$)	12	0.005–0.005	0.005	<0.05
Aluminium ($mg\,Al\,dm^{-3}$)	48	0.02–0.10	0.04	<0.2
Cadmium ($mg\,Cd\,dm^{-3}$)	12	0.0010–0.0022	0.0011	<0.005
Copper ($mg\,Cu\,dm^{-3}$)	12	0.02–0.02	0.02	<2.0
Nickel ($mg\,Ni\,dm^{-3}$)	12	0.002–0.002	0.002	<0.02
Lead ($mg\,Pb\,dm^{-3}$)	12	0.005–0.005	0.005	<0.01

4. Conclusions

(1) The mountain catchment of reservoir Wapienica is devoid of internal anthropogenic sources of environmental pollution. The fact that such a catchment provides potable water to the large city of Bielsko-Biala, is a unique case throughout Poland.

(2) Water retained in the reservoir is generally of good quality. Presence of some metals in water in amounts which suggest minor contamination may result from atmospheric deposition. Microbiological contamination also occurs periodically.

(3) According to Polish regulations, water in the reservoir is classified in category A1, which means that simple treatment is required before it is transferred to the water mains. The processes that are used include filtration and disinfection (sometimes supported with coagulation).

(4) Treated water is of very good quality which meets all requirements for potable water.

(5) Mountainous areas of southern Poland may be a source of water for which production for consumption does not require large financial expenses. This concerns especially areas not affected by anthropopressure.

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