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Original Research

An Assessment of Water Reservoirs as a Potential Sources of Pollution of the Quaternary Aquifer in Osielsko Community

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Abstract

The aim of this study was to determine environmental pollution of water reservoirs in Osielsko region and compare the results with Regional Inspectorate for Environmental Protection reports. For this purpose the water and bottom sediment samples were collected from five lakes. Main ion concentrations and trace metal levels in waters was determined by atomic absorption spectrometry (AAS). Concentrations of trace elements in sediments were estimated for fractions <0.063 mm using the ICP-MS method. It was found that the waters are slightly alkaline with electrical conductivity up to 1,025 µS/cm. The minor and trace element concentrations were usually low. The results of research suggest a correlation between size and lake location and concentration of pollutants.

Keywords: landscape transformation, migration of pollutants, Osielsko region, water reservoirs

Introduction

As a result of socio-economic transformations in recent decades, fast and permanent changes of the environment are noticeable. Degradation of natural resources has been accelerated, especially in developing countries, as a result of intensifying agriculture and further development in various branches of industrial, mining, and energy sectors. The process of urbanization has significantly contributed to the state of the environment, as cities grow and expand the surrounding landscape is changed to fit needs of their inhabitants. Rural areas surrounding industrial, trade, and administration hubs undergo transformation to provide housing and cheap living space to an increasing population, but also increasing gas and dust emissions from house heating and vehicles to the environment. The suburban population increasingly depends on services and work opportunities offered by the city; when gaps in empty space are filled, people live in an environment that physically and socially is a city [1].

All features of urbanization are noticeable in the area of Osielsko located north of the city of Bydgoszcz. The community over several years has become a vestibule of the capital city of the Kuyavian-Pomeranian voivodship. Osielsko is a clear illustration of the problems occurring while adapting rural areas to urban needs. Unfortunately, due to the rapid transformation from rural to urban landscape, it has not produced or attracted new, eco-conscious residents. Environmental awareness (or rather lack thereof), that in extreme circumstances leads to environmental degradation. The problem – often overlooked in the development plans of municipalities and communities – can lead to pollution and contamination of the aquatic environment, and most intensely the surface water. Given the hydrogeo-

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logical conditions occurring in the area of Osielsko, this situation may indirectly affect water quality of the Quaternary aquifer (groundwater captured in Niemcz, Niwy, and Żołędowo) which is currently (2013) the only exploited aquifer available to the community.

Important factor of the environment degradation is a quality of surface water, especially small water reservoirs, both natural and artificial. In an urbanized areas with intensive mining exploitation and also waste deposition the small artificial pit-lakes are strongly polluted [2-5].

This work intends to assess the degree of contamination of water reservoirs in the Osielsko community and determine their impact as potential sources of pollution of the Quaternary aquifer. Interesting geographic and hydrographic conditions of the Osielsko community determines further research and analysis.

Geological Structure and Hydrogeological Conditions

Osielsko is located in Central European province, South Baltic Lakeland subprovinces, South Pomeranian Lakeland macroregion within a few mezoregions. The largest, the central part of the community, is located within the Świecie High Plain [6]. Osielsko community is situated on the edge of the Świecie High Plain, between the river basins of the Vistula and Brda. Near the community pass watersheds of both surface (second row) waters and groundwater that determine water flow, to the west and northwest toward the Brda River and to the east toward the Vistula. Deposited contaminants spread in all directions.

Aquifers within Osielsko community occur in Quaternary, Neogene (Miocene), and the Upper and Lower Cretaceous. The inhabitants are supplied with water from three groundwater intakes located in the Żołędowo (3 boreholes), Niemcz (2 boreholes), and Niwy (1 borehole). The Quaternary aquifer is recognized in all wells by sediments: in the form of sand, mud, silt, clay, and sandy moraine of various origins. Aquifer is a major part of the community, creating a distinctive layout of the story (ground layers – subsurface, deep-seated layers – between and below clays) remaining partially in hydraulic connection.

Deep-seated layers are in fluvioglacial and glacial deposits, forming extensive fossil sandurs and small fossil valleys of various ages. Groundwater layer occurs within the modern valley of the Vistula River. Quaternary aquifer is made up of heterogranular sands, mud sand, sand with gravel and boulders, and also gravel of various origins (from south-Polish glaciation through middle Odra and Warta glaciation, Vistula glaciations, and Eemian and Mazovia interglacial to Holocene). The average depth of deposition of Quaternary sediments differs – from less than 5 m in the valley of the Vistula to 15-50 m in most parts of the area. Confined groundwater is conducted thru Quaternary sediments and drained by Brda to the west and northwest, and by Vistula to the east (hydrogeological mapping results July, August 2010). The discussed aquifer has good hydrogeological parameters. Average thickness of sediments ranges from 20 to 40 m. Water permeability ranges from 200 to 500 m^2/day. Average well discharge is in the range of 30 to 50 m^3/h.

The Quaternary aquifer is isolated by tills cover. It dominates an average of groundwater endangering. Unfortunately, there is lack of continuous leak of tills cover aquifer. It determines fragmentarily high groundwater endangering, the impact of anthropogenic pollution. These conditions sparked an idea for research on the reservoirs as potential sources of pollution affecting water quality in the Quaternary aquifer. There is a connection between the surface and groundwater. Between water reservoirs and the

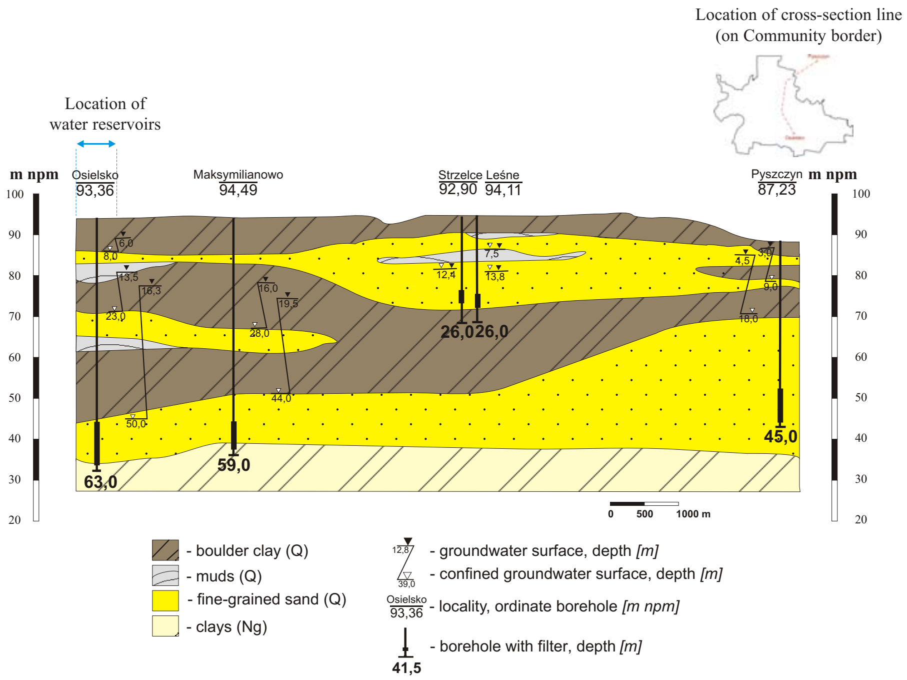

Fig. 1. Hydrogeological cross-section of Osielsko-Pyszczyn, [8] modified.

Quaternary aquifer is hydraulic contact. These reservoirs can be supplied and drained by underground water. Their character was emphasized by groundwater flow direction on Fig. 2.

Sediments in the southern part of Osielsko are mainly clays of various origins, forming several meters of compact board. Toward the southeastern part of the area, to the Vistula Valley, sediments are dominated by sand, mud sand, and mud with high thickness range of 20-40 m, with almost no tills. In the northern and central part of the community Quaternary profile is more diverse. At the top the most common part is covered by several meters of sandy clay, mud, Holocene, and Vistula glaciation mud sand. Below arrears the sands, silty sand, sand with gravel, boulders, and also layer of several meters of mud from Vistula and Odra glaciation. In the bottom layer are mostly south-Polish glaciation deposits (Fig. 1) – tills, silty clays, sand, and several meters of mud [7].

Research Methodology

The aim of this study was to estimating contamination levels of water reservoirs in the Osielsko region. For this purpose, the water and bottom sediment samples were collected from five lakes during summers 2010. The electric conductivity (EC), redox potential (Eh), pH value, and temperature of the water were measured *in situ*. Chemical analysis of the water included measuring concentrations of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^-, Cl^-, SO_4^{2-}, PO_4^{3-}), as well as trace metals (Fe^{2+}, Mn^{2+}) by the titration, colorimetry and AAS methods (spectrometer Philips PU-9100x). Chemical analysis of water was carried out in an accredited hydrogeochemical laboratory in the Department of Hydrogeology and Engineering Geology of AGH University.

In the collected sediments, the concentrations of trace elements (As, Cd, Cu, Cr, Ni, Pb, Zn) were estimated in fraction <0.063 mm using ICP-MS methods (Perkin Elmer Elan 6100 spectrometer), and the content of fine particles was determined by sand ratio test in accordance with Polish Standards (PN-EN 933-8:2001). ICP-MS measurement was performed on solutions obtained after the dissolution of metals in nitric acid.

For a full diagnosis of the functioning of water reservoirs in the hydrological and hydrogeological system, it is necessary to continue research. Also, measurement series should be repeated.

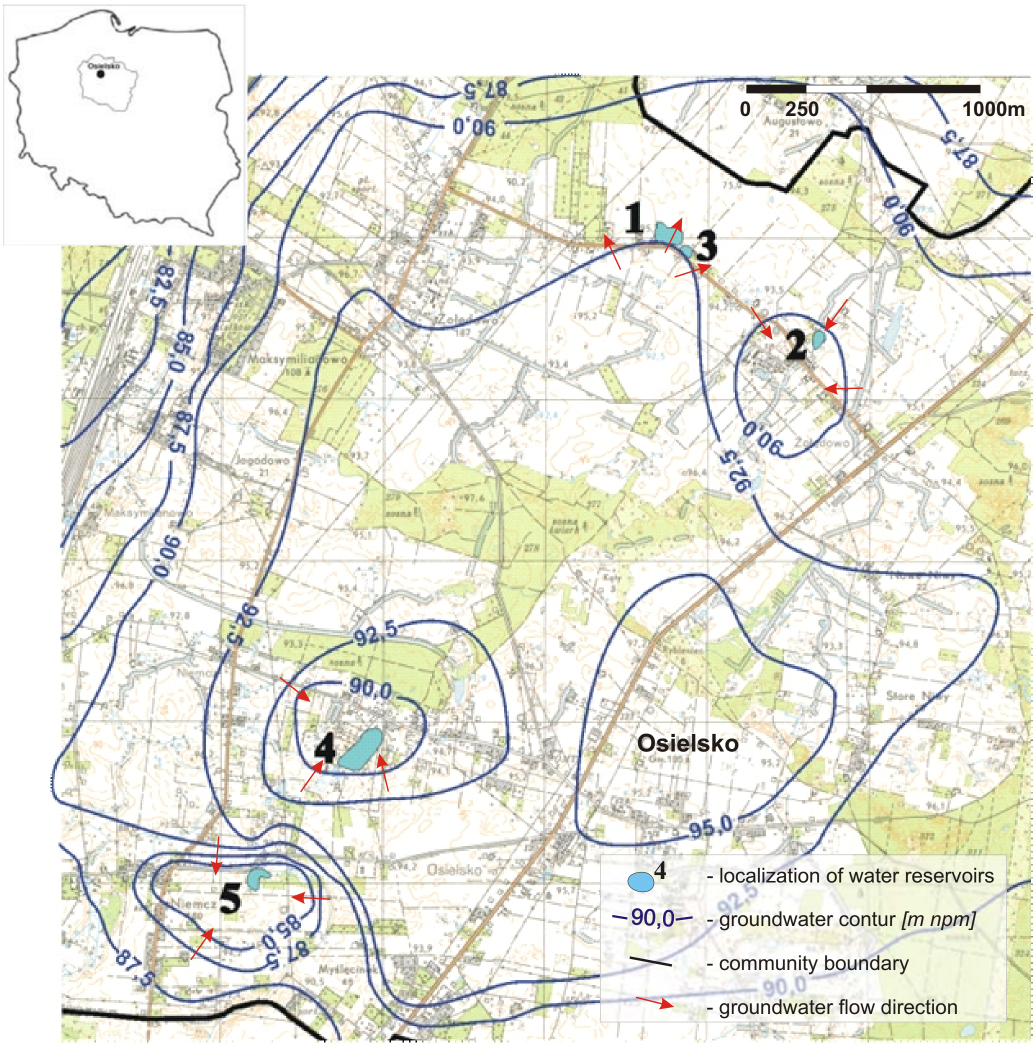

Fig. 2. Map of a Quaternary aquifer with typed water reservoirs [9] on [10].

Table 1. Morphometry of lakes – characteristics of the area of lakes.

Sampling point	Area F [m^2]	Length L [m]	Average width B_{av} [m]	Maximum width B_{max} [m]	Elongation rate λ	Length of coastline l [m]	Development of the shoreline K
1	1,248.00	67.00	18.6269	50.00	3.5970	184.00	1.4697
2	1,883.00	70.00	26.9000	62.50	2.6022	215.30	1.4000
3	705.00	58.00	12.1552	37.00	4.7716	155.90	1.6567
4	16,400.00	260.00	63.0769	89.50	4.1220	637.80	1.4053
5	466.00	63.00	7.3968	34.20	8.5172	76.60	1.0012

Table 2. Morphometry of lakes – characteristics of the lake basin.

Sampling point	Volume V [m^3]	Maximum depth H_{max} [m]	Average depth H_{av} [m]	Relative depth H_w [m]	Indicator of the depth W_Θ	Indicator unveiling W_o
1	1622.40	1.70	1.30	0.0481	0.7647	960.00
2	1506.40	1.00	0.80	0.0230	0.8000	2353.75
3	775.50	1.30	1.10	0.0490	0.8462	640.91
4	36080.00	2.60	2.20	0.0203	0.8462	7454.55
5	745.60	1.90	1.60	0.0880	0.8421	291.25

Physical Characteristics of Water Reservoirs

The study area is located within the boundaries of north-Polish glaciation with the resulting geomorphological, hydrographic, and soil consequences. It is reflected in the types of landscape – valley and early post-glacial landscapes. Dune valley landscape is characterized by asymmetric profile glacial forms. Northern slopes are mostly steep, southern slopes are generally gentler. Typical features of the early post-glacial landscape are, in addition to varied relief, numerous lakes, small pounds, cave-in depressions, basins left by frontal and bottom moraine which currently are filled with mineral and organic sediments.

Therefore, five water reservoirs in the Osielsko community were selected for detailed study. Researched lakes are primarily located in the center, in the area transformed from rural to urban landscape, without woods and away from the meadows and pastures (Fig. 2).

In order to investigate measurable pollution load, water reservoirs with relatively small areas were selected (Tables 1 and 2), so that the deposited components were not significantly diluted and washed. Three of the lakes are located in the northern part of the community in the vicinity of Żołędowo, the other two southwest of them, around Osielsko.

Field work was carried out in July, August 2010. The study area covers an area of approximately 103 km^2. During the field research was carried out bottom sediments and water sampling and also hydrogeological sampling (Fig. 2). Measurement of residual water level in dug wells (90 sampling points in Osielsko community) and listing of pollution sources that threaten the environment were performed during the dry period – in the heat of summer with no or intermittent precipitation. Groundwater level in the course of the measurements was low. Measurement of residual water level was generally performed in active wells.

Due to geological structure shallow groundwater circulation is dominating. Two northern surface water reservoirs (points No. 1, 3), which are the subject of our research are infiltrating. In those places water balance consist of groundwater inflow and precipitation, evaporation and outflow. The other three reservoirs (points No. 2, 4, 5), located in the central part of the community, are local drainage bases for Quaternary groundwater. Here water revenue consists of precipitation and groundwater inflow while outflow is determined by an evaporation process.

Chemical Characteristics of Water Reservoirs

Characterized water is slightly alkaline – pH value (7.70-8.36). The redox potential (Eh) ranges between 271-308 mV and electric conductivity (EC) varies in a wide range, 359-1,025 µS/cm (Table 3). The values of this parameter indicate different mineralization, the amount of soluble components in the water and the potential pollution.

The full results of the chemical analyses are shown in Table 4. There are no studies of the biological elements and physico-chemical indicators supporting the biological elements necessary to classify lakes. This forced use of the repealed regulation of the minister of the environment [11]. Therefore, we cannot assess the degree of pollution of these lakes based on the current regulations.

Table 3. Physical and chemical parameters of water.

Parameter	Unit	Lake No.				
		1	2	3	4	5
EC	µS/cm	606	428	1025	808	359
pH	-	8.16	7.70	8.36	8.02	7.97
Eh	mV	306	271	293	308	290
Temperature	ºC	8.9	7.9	8.1	8.0	9.5

The main cation in lake waters in Osielsko is calcium, with the highest concentration recorded at sampling point No. 5 (119.29 mg/dm³). The lowest concentration of the element has been noted in point No. 4 (50.36 mg/dm³). Calcium concentration in all five lakes exceeds the limit (50 mg/dm³) set for first-class water quality. Other cations are present in significantly lower amounts (Table 4). Especially noteworthy are concentrations of boron and magnesium cations. Boron concentration is acceptable for second-class drinking water in sampling point No. 1 (0.91 mg/dm³), the same applies to magnesium in sampling point No. 3 (Mg^{2+} 32.87 mg/dm³). However, concentrations registered for anions are higher: HCO_3^- in the range up to 575.84 mg/dm³, Cl^- to 66.70 mg/dm³, SO_4^{2-} to 46.13 mg/dm³ and PO_4^{3-} to 3.68 mg/dm³ (Table 4).

According to Altowski-Szwiec classification, water in the lakes has bicarbonate-calcium-magnesium (HCO_3-Ca-Mg) chemical type. Lake No. 1 impounds bicarbonate-chloride-calcium (HCO_3-Cl-Ca) water. General mineralization is varied and ranges in value 324.92-925.76 mg/dm³. As shown (Tables 2 and 4) its value is directly proportional to the size of the studied lakes (volume of retained water). It follows that the discharge of pollutants into the reservoir is diluted and washed.

To illustrate the chemical type of water analysis results are presented in Piper's diagram (Fig. 3). Hydrogeochemical background of Quaternary aquifer (maximum and minimum values) and results of chemical analyses of water from two large-scale lakes (closest to the study area) are provided on the diagram. These two lakes are located in Bydgoszcz district and are monitored by the Regional Inspectorate for Environmental Protection (RIEP)

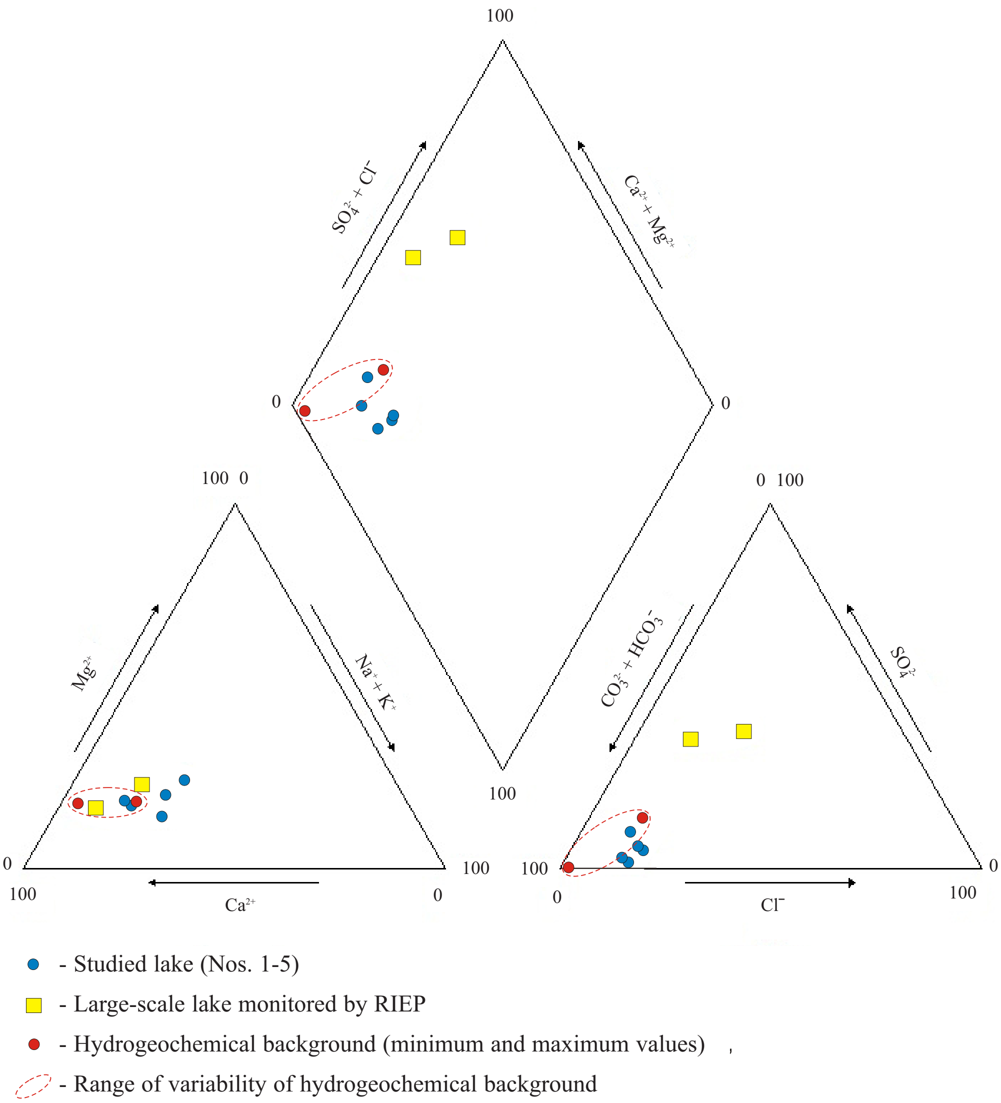

Fig. 3. Piper's diagram.

Table 4. The results of chemical analysis of water.

Lake No.	1	2	3	4	5
Component \ Unit	[mg/dm³]				
Al	0.0008	0.0006	0.0011	0.0012	0.0005
As	0.0000	0.0001	0.0004	0.0000	0.0001
B	0.9119	0.3406	0.2725	0.1525	0.0908
Ba	0.0051	0.0071	0.0198	0.0243	0.0193
Be	0.0000	0.0000	0.0000	0.0002	0.0001
Bi	0.0000	0.0001	0.0001	0.0003	0.0003
Br	0.0000	0.0000	0.0164	0.0000	0.0063
Ca	52.3111	71.9560	113.2085	50.3593	119.2873
Cd	0.0000	0.0000	0.0000	0.0001	0.0000
Co	0.0001	0.0002	0.0003	0.0001	0.0003
Cu	0.0021	0.0005	0.0009	0.0015	0.0009
Fe	0.0018	0.0409	0.0123	0.0058	0.0213
Ga	0.0001	0.0002	0.0006	0.0009	0.0006
Hg	0.0007	0.0004	0.0007	0.0025	0.0011
K	17.5237	35.7867	61.6015	7.6417	11.5700
Mg	7.3980	15.7839	32.8686	8.0611	20.0024
Mo	0.0003	0.0000	0.0001	0.0005	0.0000
Na	15.4370	14.5234	31.9371	10.5727	23.5328
Ni	0.0005	0.0007	0.0013	0.0005	0.0011
Pb	0.0000	0.0000	0.0000	0.0001	0.0001
Rb	0.0018	0.0065	0.0302	0.0028	0.0039
Sb	0.0000	0.0000	0.0001	0.0009	0.0002
Se	0.0000	0.0000	0.0000	0.0012	0.0000
SiO_2	0.2738	3.2360	8.7439	2.7879	13.5676
Sn	0.0000	0.0000	0.0000	0.0000	0.0001
Tl	0.0000	0.0000	0.0000	0.0001	0.0000
U	0.0004	0.0002	0.0005	0.0002	0.0001
W	0.0000	0.0000	0.0002	0.0006	0.0002
Zr	0.0000	0.0001	0.0003	0.0005	0.0004
HCO_3^-	236.04	368.54	575.84	218.82	475.07
Cl^-	31.639	40.200	66.703	20.845	42.880
PO_4^{3-}	1.914	3.676	1.279	0.000	0.376
SO_4^{2-}	10.851	5.816	33.223	5.638	46.133
Mineralization	374.312	559.914	925.762	324.921	752.565
Analysis error [%]	5.11	5.42	2.80	6.31	4.73

Table 5. Heavy metals in analyzed bottom sediments.

Lake No.	1	2	3	4	5
Metal \ Unit	[mg/kg]				
Zn	48.53	23.30	29.73	20.01	33.50
Fe	5,922.73	2,520.64	2,303.12	860.96	1,629.60
Mn	92.36	21.41	24.61	13.25	32.99
As	0.52	0.24	0.25	0.13	0.45
Cr	9.38	3.33	3.00	2.75	4.03
Cd	0.18	0.04	0.05	0.09	0.19
Pb	7.06	2.48	3.57	6.13	6.67
Ni	5.19	2.42	3.54	1.65	6.72
Cu	11.11	2.89	3.58	3.92	5.30
Hg	0.00	0.02	0.04	0.00	0.05

in Bydgoszcz. Wierzchucińskie Małe Lake covers an area of 52.3 ha, which included 3rd class water quality and 2nd category degradability. In addition, the lake is eutrophic and waters are chemically calcium-bicarbonate-chloride (Ca-HCO_3-Cl). Borówno Lake covers an area of 43.2 ha and its waters are the same class type and category as the above. It is mesotrophic lake [12].

Particular attention is paid to phosphate content in water. Lakes 1, 2, and 3 contain high amounts of dissolved phosphate (1.28-3.68 mg/dm^3), classifying water to 5th-class quality. Average phosphorus content in the lakes 1, 2, and 3 are as follows: 0.62 mg/dm^3, 1.20 mg/dm^3, and 0.42 mg/dm^3.

The content of total phosphorus in the samples ranges from 0.00 to 1.20 mg/dm^3. The eutrophication of lakes occurs at the total phosphorus concentration above 0.25 mg/dm^3, and applies to lakes 1, 2, and 3 (5th class). Eutrophication is the enrichment of water by biogenes, in particular compounds of nitrogen or phosphorus. This results in accelerated growth of algae and higher forms of plant life. Interference in biological relationships in the aquatic environment is undesired, and deteriorates quality of water [13].

Of the 59 lakes in the Kuyavian-Pomeranian voivodship monitored by RIEP (2005) in Bydgoszcz, 78% are eutrophic lakes. The content of phosphate, nitrate, and turbidity are the only physico-chemical indicators, which is determined by the trophic degree water reservoirs. The process of eutrophication also was strong in the Osielsko area. During the field research we observed numerous

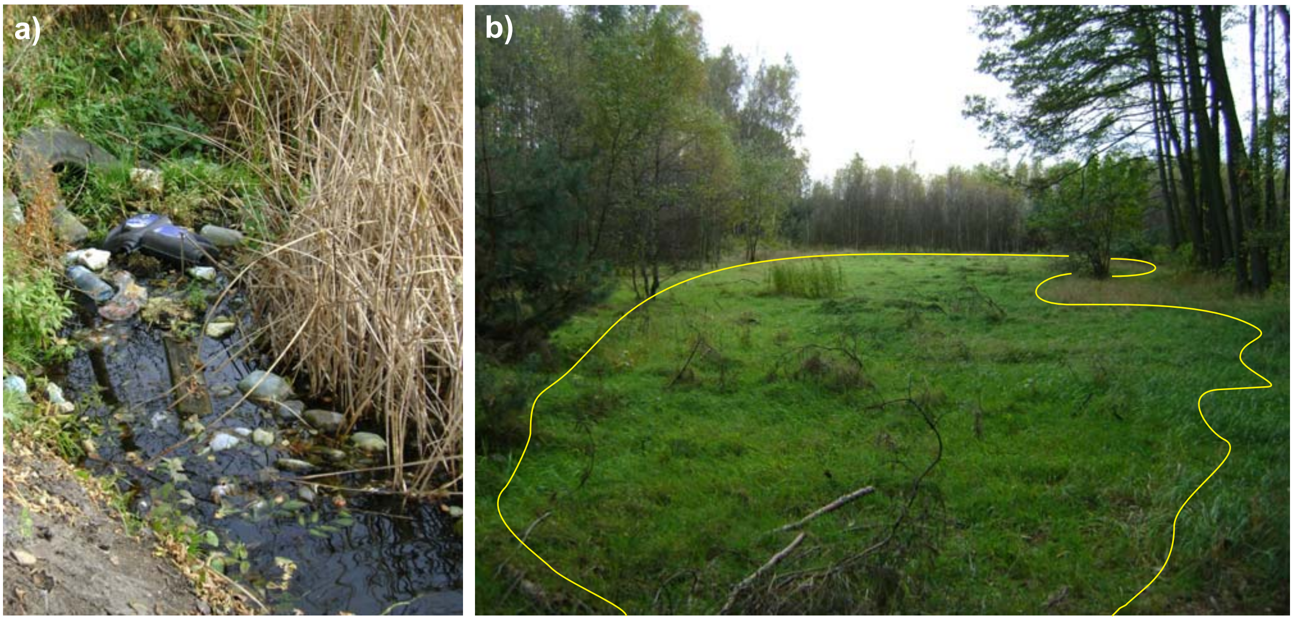

Fig. 4. (a) Source of surface water pollution and (b) overgrown lake with the former shoreline – white line (by Pietrucin)

traces of the overgrown lakes and reservoirs in the process of overgrowing (Fig. 4). Phosphates migrate into water reservoirs with surface flow. This water contains traces of phosphates used in detergents (80% in Poland), phosphatic fertilizers, and municipal and domestic wastewaters. Due to the location of lakes and land development, phosphates from soil erosion, precipitation or decay, and dissolution of minerals containing phosphorus do not affect the final concentrations indicated in the water from reservoirs. Low ecological awareness aspects, such as the discharge of domestic sewage and decomposition of animal remains, enhance degradation of surface waters.

In order to ensure that pollution by heavy metals has not fallen to the bottom of the studied lakes and, therefore, they are not in the water content, bottom sediments were tested (Table 5). Using plasma emission spectroscopy (ICP-MS), content of select heavy metals has been determined for fraction <0.063 mm of surface layer of the bottom sediments. The measurement results are shown in Table 5.

In sediments that have geogenic origins in this area of Poland we have found the dominant content of iron (860.96-5922.73 mg/kg) and manganese (13.25-92.36 mg/kg). Other trace-metal concentrations in the bottom sediments are usually low and depend on the lake location. The concentrations in mg/kg are as follows: Zn – 20.01-48.53, As – 0.13-0.52, Cr – 3.00-9.38, Cd – 0.04-0.19, Pb – 2.48-7.06, Ni – 1.65-6.72, and Cu – 2.89-11.11 mg/kg (Table 5).

The origin of heavy metals, including lead and mercury, is associated with urban communities. Potential pollution comes from vehicle exhaust and waste along roads. Mercury is detected in fuel. In the case of nickel, it is mainly used as a steel cover, which increases strength and corrosion resistance. Steel of this type is used in the automotive industry.

Sediment studies show that heavy metals in the sediments do not exceed the limits for first class waters. Sediments are not contaminated according to geochemical [14] and LAWA classifications [15]. However, cautioned about the possibility of severe contamination of Quaternary aquifer in the case of concentrated discharge of pollutants into water reservoirs the sand ratio test (carried out on samples of bottom sediments) shows that it is a sandy material 66.9-74.8% (a study carried out in an accredited laboratory of rocks property research and stone products, AGH University) infiltrating-draining lakes with good basis hydrogeological parameters facilitating the migration of contaminated water from the lake into the aquifer. They are a hydrogeological window and also the source of pollution.

Conclusions

The aim of this study was to determine environmental pollution of water reservoirs in Osielsko region. Therefore, sampling of small natural water reservoirs and measurable analysis of aquatic environment pollution was performed. Because of hydraulic contact with the aquifer, accumulated chemical compounds begin to migrate into the aquifer in the direction of groundwater flow. Thus, changing water chemistry in relation to the hydrogeochemical background values, which represents potential contamination.

The lakes are slightly alkalic (7.70-8.36), with medium mineralization and electrolytic conductivity of 359-1,025 μS/cm. Waters usually represent the bicarbonate-calcium type according to Altowski-Szwiec classification. Trace-metal concentrations in the bottom sediments are usually low and depend on the lake location. Elevated levels of Fe^{2+} and Mn^{2+} are the result of natural geochemical processes and have geogenic origins.

The phosphate and nitrate concentration in waters from the Osielsko region suggest that the pollution is probably caused by the agriculture (e.g. fertilization) and industrial sector. Those parameters also show the trophic degree of the water reservoirs. The process of eutrophication was appreciable during field investigations. The results strongly suggest that sampling and monitoring smaller water reservoirs allow measurement of contamination and thus tracking variability of chemical composition of these waters. In addition, monitoring of small lakes will help identify more precisely pollution degree. We find it plausible that an increased reservoir volume may affect the proportional decrease in harmful substances concentrations.

Fortunately, reservoirs represent good quality water and uncontaminated sediments. Therefore, it is considered that at the time of the study, these reservoirs were not pollution sources. Mention of the need for further research and raising ecological awareness of the Osielsko population is necessary.

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