PROTECTION OF WATER RESOURCES IN RECREATIONAL AREAS IN URBAN SPACE

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ABSTRACT

Access to recreational areas is particularly important in the context of improving the quality of life in cities. One of the valuable elements of such areas may be water reservoirs and their accompanying springs. An example of such a recreational area is the so-called Palowice Lake District (southern Poland), which includes three water reservoirs, ten breeding ponds and two springs from which water is taken. Water from the springs is considered to be of very good quality and is regularly consumed by residents of nearby towns as well as tourists. The quality of these waters is influenced by natural factors such as weathering of rocks, evapotranspiration, atmospheric deposition, climate change, but also by anthropogenic factors such as industrial effluents, domestic activities, tourist traffic and agricultural activities. However, the results of research conducted in the area of the springs indicate the presence of E. coli and enterococci in the water. The latter are characterized by longer survival in water. Consuming such water may lead to the development of numerous digestive system diseases, hence the issue of protecting water resources in urbanized areas, including conducting representative monitoring of the quality of these waters, is extremely important.
Keywords: water, spring, quality, bacteriology, human health, Poland.

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INTRODUCTION

Sustainable urban development is one of the most serious issues in the 21st century [1]. Spatial development, including access to recreational areas, is an important element in the context of assessing the quality of life in urban areas [2]. With the popularity of recreational activities such as walking or cycling trips within and across cities, using nature and technological monuments for recreation purposes has become a common phenomenon [3,4,5].

With the increase in the number of tourists and the increasing urbanization, environmental problems appear in recreational areas in terms of soil, water, air pollution and problems related to waste management [6,7,8,9].. It is assumed that only 3% of water resources are in their natural state [10]. This is a significant problem causing water shortages and increased pollution of the soil and water environment. One in four large cities (population > 750,000) is water stressed (water use / availability ratio > 0.4; [11]). Water is the largest consumer product, which is also essential for the development and organization of cities [12]. The urbanization process causes pressure on water resources and changes the hydrological regimes of watercourses [13]. Cities' water resources should be constantly strengthened by conducting rational water management and developing good practices in water resources management [14]. Sustainable development in the context of maintaining the quantity and quality of water resources in urban space is the subject of numerous studies [15,16,17].

Surface waters are one of the main sources of water supply for people, and maintaining their quality is of great importance. Additionally, spring waters and groundwater are used in deficit areas [18,19] Springs deserve special attention due to the element connecting surface and groundwater ecosystems, which are particularly exposed to pollution [20,21]. This applies not only to karst areas [22], but also to recreational areas in urban areas [23].

The amount of pollution in spring waters may be influenced by the topography of the land, the method of spatial development in the spring area, but also the amount of precipitation or the presence of a nearby sewage system [24,25,26] Sources of pollution in spring may be located in the surface water catchment area or from external sources. Mobilization of components may occur in the presence of processes such as desorption, mineralization, erosion and landslides, and the decomposition of organic matter or nutrient cycling. The recreational function of springs can also lead to an increase in pollution. This applies not only to inorganic pollutants, but also to the number of microorganisms. Although spring water can have positive effects on human health, pollution and poor sanitation can have a negative impact on health, causing numerous digestive diseases [27].

Springs in recreational areas in urban space should be subject to water quality monitoring in order to determine changes in the size of physicochemical and microbiological parameters and to determine the factors that may cause these changes. Based on monitoring data, it is possible to assess the risk for these waters, e.g. based on indicator methods [28,29]. One example of such indicators is the Water Quality Index (WQI), which is based on only a few parameters.

The scale of this indicator involves assigning weights to various water quality parameters based on their permissible values for drinking water [30]. The upper limit of the natural hydrogeochemical background or the values for one of the water quality classes based on the relevant regulation can also be used as reference values. A separate issue is the bacteriological parameters that can be compared with standards for drinking water.

The research was conducted in the waters of two springs (names: Dobro Woda, Święto Woda) located in the urban area of the Palowice Lake District (southern Poland). The research took place in two measurement series in November 2023 and February 2024. The research results indicate that, despite the fact that the water in the springs is regularly consumed by local residents and tourists, it contains bacteria that may negatively affect the digestive system and pose a threat.

STUDY AREA

The subject of the research are the waters of two springs- Dobro Woda (Fig. 1) and Święta Woda (Fig. 2), which are located within the so-called Palowice Lake District located between the town of Żory and the town of Palowice (southern Poland). The lake district is located within the Silesian Upland macroregion and the Katowice Upland mesoregion [31]. The Palowice Lake District is located in the "Cistercian Landscape Compositions of Rudy Wielkie" Landscape Park and consists of 10 breeding ponds and three post-excavation reservoirs with a total area of 57 ha. The entire complex is located in the Jesionka stream valley and Ruda river (Fig. 1). The Lake District area is used for recreation all year round. There is a 3.5-kilometer ski and educational trail here, which is also used by pedestrians and cyclists. Additionally, there is a 34-kilometer bicycle loop running through forest areas, excluding car traffic.

Fig. 1 Outflow of the Dobro Woda spring.

Fig. 2 Outflow of the Święto Woda spring.

This area was highly industrialized in the past. In the Lake District there are remains of the Waleska steelworks in the form of a 15-meter tower called Gichta. The steelworks operated in this place until 1855. The ponds are the remains of open-pit mining of morass ore.

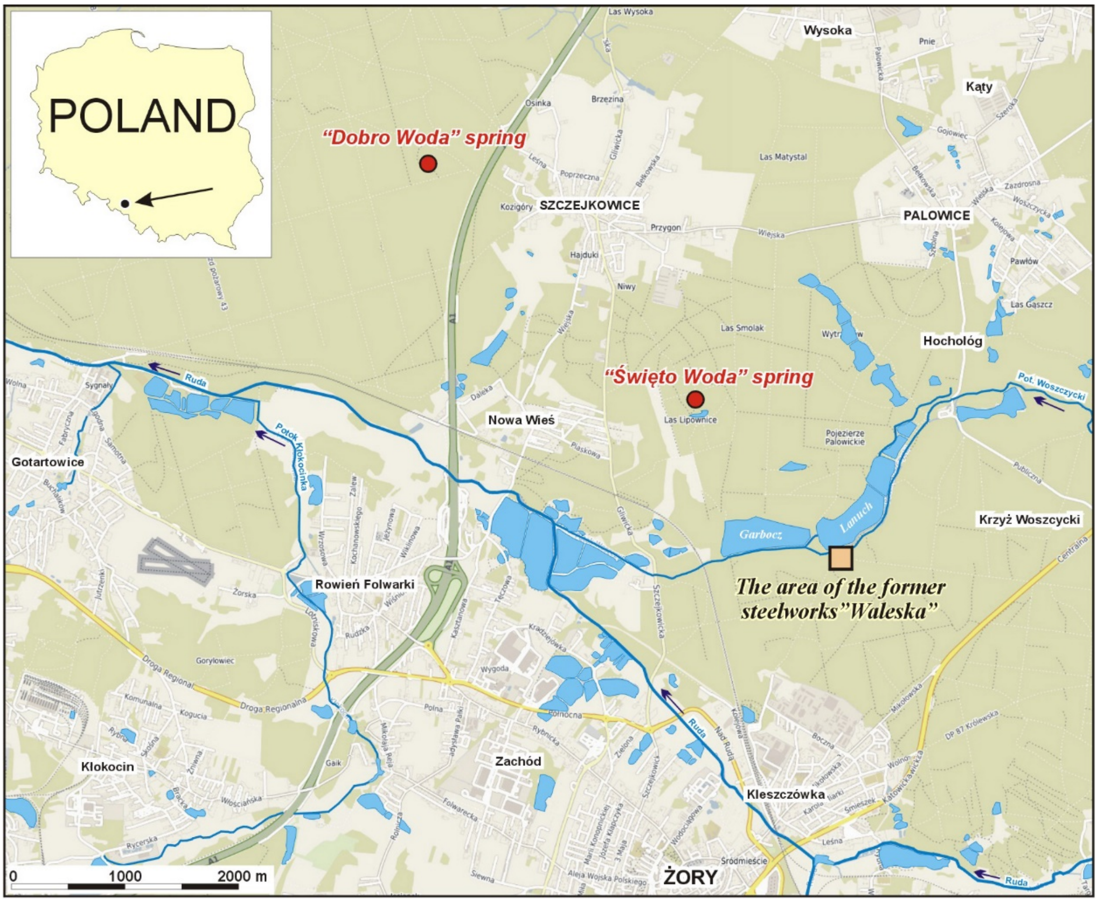

Fig. 3 Study area.

The research area is located in the Upper Silesian Coal Basin, which is associated with the Variscan and Alpine orogeny. In the area of the sources, the Upper Carboniferous coal-bearing series is composed of sandstones, siltstones and claystones, among which there are deposits of hard coal. The geological profile includes a paralic series - mudstones and claystones predominate over sandstones; the Upper Silesian Sandstone Series, which consists of layers of sandstones and coal seams as well as claystones and mudstones, then the Siltstone Series, which is dominated by mudstones and claystones, and the Krakow Sandstone Series, which consists of weakly compact sandstones, conglomerates, and mudstones. The thickness of Carboniferous sediments is approximately 860 m. Neogene deposits lie directly on the Upper Carboniferous deposits. These are mainly Miocene deposits developed in the form of marly clays with a gypsum-salt series in the roof. Plasters are the most widespread. Quaternary formations are characterized by discontinuous distribution and variable thickness, from several to 100 m. The largest thicknesses of these formations reach up to 100 m. They are formed mainly in the form of Pleistocene glacial sands and gravels of the Central Polish glaciations. There are also loesses associated with the Vistula glaciation. In the river valleys there are alluvial deposits, clays, sands and gravels of river accumulation with a thickness of up to 5 m, lying directly on the gravels and sands of the Central Polish glaciations.

There are three aquifers in the hydrogeological profile of the analyzed area: the Quaternary, Neogene and Carboniferous aquifers. The Quaternary aquifer usually forms one level, locally separated by clay and clay inserts. The depth of the water table depends on the terrain and ranges from 2 m in valleys to 10–20 m in hilly areas. The water table is usually unconfined, only locally confined. The hydraulic conductivity of aquifer-bearing Quaternary sediments range from 7.21×10^{-2} to 172.8 m/d. Hydrogeological properties of the gravel and sand complex filling the valley forms are up to 77.0 m thick, while in the coastal part of the valleys they are 10–20 m thick [32]. The Quaternary aquifer is recharged by atmospheric precipitation and, locally, by surface streams. The basis of drainage is river valleys and groundwater intakes [33].

The Neogene aquifer is composed of lenses, beds and laminates of sand and silty formations occurring in a compact, almost impermeable complex of clays. The thickness of clay deposits is variable and reaches up to 300 m. Sandy layers are up to approximately 140 m thick. Hydraulic conductivity reaches the value of 0.1–0.01 m/d. Recharge of the Neogene aquifer is very limited. At shallow depths, it takes place indirectly by infiltration through permeable Quaternary formations, while deeper relict waters dominate.

The hydration of Carboniferous layers is not influenced by water from the overlying aquifers due to the surface isolation by a continuous series of impermeable Neogene clays. Hydraulic conductivity value ranges from 8.64×10^{-5} to 3.02×10^{-1} m/d. The aquifer occurs at a depth of up to 1,000 m.

METHODOLOGY

The research in Springs included two measurement series conducted in November 2023 and February 2024. During field trips, water samples were collected for physicochemical and bacteriological analyses. Physicochemical and bacteriological analyzes were performed in an accredited laboratory. In terms of physicochemical parameters, the values of electrical conductivity, pH, Ca, Na, K, Mg, Fe, Al, Mn, Ni, Cu, Sr, S, Cl, SO_4, HCO_3, NO_3, NO_2, NH_4, PO_4, N, TOC, Pb, Cd, Cr, Hg, Zn, acidity and alkalinity. The potential presence of pathogens in environmental waters was inferred based on the determination of coliforms, enterococci, P. aeruginosa and C. perfringens.

Due to the fact that water from both springs is collected by tourists and local residents, the Water Quality Index was calculated for each point in both measurement series in order to determine the risk to water. The Water Quality Index (WQI) is one of the most optimal ways to describe water quality and assess water risk. The indicator was first used by Horton (1965). All parameters are assigned weights based on their health impact [30]. The calculation of this indicator includes the following stages: (i) assigning weights to physicochemical parameters, (ii) developing a rating scale and (iii) calculating WQI. The computation of relative weights (Wi) is as follows (1):

$$W_i = \frac{w_i}{\sum w_i} \qquad (1)$$

where w_i is the weight values for parameters.

After that, calculating the quality rating scale (qi) is performed using eq. 2:

$$q_i = \frac{C_i}{S_i} \cdot 100 \qquad (2)$$

where:
C_i is the concentration of parameters,
S_i is the standard value of parameters.
WQI is calculated using the following equation:

$$WQI = \sum_{n=1}^{N} SI \qquad (3)$$

where:
SI is the subindex calculated from the (4) eq.:

$$SI = W_i \cdot q_i \qquad (4)$$

The traditional approach to WQI takes into account 9 parameters whose sum of weights has a value of 100. These parameters are dissolved oxygen, fecal coliform, pH, biochemical oxygen demand, temperature change, total phosphate, nitrates, turbidity and total solids [34]. Due to the fact that not all parameters were determined for the waters in the springs. WQI was calculated for the following ingredients and assigned appropriate relative weights: dissolved oxygen (0.22), total number of microorganisms at 22±2°C (0.21), pH (0.15), total phosphate (0.13), nitrates (0.13), EC (0.16). The index classifies water into the following classes: WQI < 50: excellent water; 50–100 WQI: good water; WQI > 100: poor water.

RESULTS AND DISCUSSION

The obtained biological and physicochemical values were compared to the quality standards of water intended for human consumption and Water Quality Index values were calculated for six parameters. The value of specific electrolytic conductivity was 180 µS/cm in the first measurement series, and 172 µS/cm in the second series for the Dobro Woda Spring and respectively 175 and 150 µS/cm for the Święta Woda Spring. The values of most parameters were in most cases a dozen or so percent of the norm for drinking water and for the I class of water quality (Table 1).

In general, the pH of water samples from springs is lower than the optimal pH values (6.5–8.5) set in the mentioned regulations as well as those set by WHO [35]. There was no pH-temperature rule for both sources. In Dobro Woda spring, lower pH was observed at higher temperature, and in the second source it was the other way around. It should be noted that the reduced pH of groundwater is characteristic of this region. The calculated alkalinity values in November 2023 and February 2024 for the first source were 5 mg CaCO3/l, and for the second source they were approximately 24 and 16 mg $CaCO_3$/l, respectively. These are very low values, similar to rainwater. In case of low alkalinity value of drinking water, corrosion of metal pipes, fittings and metal elements of heat exchangers and other devices is possible.

Tab. 1

Results of analyzes for the Dobro Woda (I) and Święto Woda (II) Springs.

Parameter	Unit	I (1)	I (2)	II (1)	II (2)	Limits for drinking water	Limits for the first class of quality
EC	µS/cm	180	172	175	150	2500	700
Na	mg/l	4.4	5	5.3	5.1	200	60
K	mg/l	2.4	2.3	1.9	1.8	-	10
Ca	mg/l	20	27	25	26	-	50
Mg	mg/l	5.3	7.2	4.5	5.4	125	30
Fe	mg/l	0.042	0.11	0.2	0.33	0.2	0.2
Al	mg/l	0.093	0.13	0.23	0.49	0.2	0.1
Mn	mg/l	0.019	0.033	0.066	0.095	0.05	0.05
Ni	mg/l	0.011	0.006	0.005	0.007	0.002	0.005
Cu	mg/l	0.002	0.011	0.002	0.007	-	0.01
Sr	mg/l	0.18	0.19	0.15	0.13	-	
S	mg/l	18	19	14	13	-	
Cl	mg/l	8	8	13	9	250	60
SO_4	mg/l	63	70	50	44	250	60
HCO_3	mg/l	6	6	29.1	20.6	-	200
NO_3	mg/l	1.5	2.8	3	6.7	50	10
NO_2	mg/l	0.033	0.033	0.033	0.033	0.5	0.03
NH_4	mg/l	0.065	0.065	0.065	0.065	0.5	0.5
PO_4	mg/l	0.025	0.025	0.025	0.025	-	0.5
N_K	mg/l	2.5	2.5	2.5	2.5	-	
TOC	mg/l	2.8	2.1	9.1	8.6	-	5
Pb	mg/l	0.002	0.002	0.002	0.002	0.01	0.01
Cd	mg/l	0.00025	0.00025	0.00025	0.00025	0.005	0.001
Cr	mg/l	0.0015	0.0015	0.0015	0.0015	0.05	0.01
Hg	mg/l	0.00005	0.00005	0.00005	0.00005	0.001	0.001
Zn	mg/l	0.023	0.047	0.048	0.1	-	0.05
Acidity	mmol/l	0.1	0.78	1.1	0.1	-	
Alkalinity	mg/l $CaCO_3$	5	5	23.9	16.9	-	
Dissolved oxygen	mg/l	7.8	10.9	9.2	11	8	
pH		5.54	6.05	5.86	5.6	6.5-8.5	6.5-9.5
The number of coliform bacteria	jtk/100ml	10	0	35	0	0	
Number of Escherichia coli	jtk/100ml	4	0	13	5	0	
Number of Enterococci	jtk/100ml	6	0	0	0	0	
Number of Clostridium perfringens	jtk/100ml	0	0	0	0	0	

cont. Tab. 1

Results of analyzes for the Dobro Woda (I) and Święto Woda (II) Springs.

Total number of microorganisms at 22±2°C	jtk/ml	>300	>300	>300	>300	100
Number of Pseudomonas aeruginosa	jtk/100ml	0	0	0	0	0
Total number of microorganisms at 36±2°C	jtk/ml	22	0	29	38	20

DO values in first and second measurement series for Dobro Woda spring and Święto Woda spring were equal to 7.8-10.9 mg/l and 9.2-11 respectively. The DO value was generally stable between collection periods but it was higher than the standards. Dissolved oxygen plays a significant role in biological processes for organism physiology and it makes that water taste is better but unfortunately it causes corrosion in water pipes.

More polluted water is found in the Święto Woda spring. However, increased concentrations of some components were also observed in the Dobro water spring. Exceeding the permissible values in relation to the standards for water intended for drinking or for the first class of water quality was recorded in the case of concentrations of iron, aluminum, manganese, nickel and total organic carbon. Additionally, decreased water pH and coliform bacteria were observed. The occurrence of increased iron and manganese content here is related to the former mining of bog ores. It should be borne in mind that large amounts of iron in groundwater may not only be toxic to humans through water consumption, but also toxic to plants. Additionally, it should be noted that bog iron ore deposits may influence local hydrological conditions as they may form an impermeable layer in the shallow subsoil [36]. Drinking water with high concentrations of manganese may cause health problems such as bronchitis, Parkinson's disease and neurotoxicity [37]. However, nickel is much more toxic. Nickel can be found in minerals usually with sulphur and arsenic. It can be also connected with wastewater from metal surface treatment and wastewater from colour metallurgy. Exposure to high concentrations of nickel in water can cause respiratory problems, skin irritation, and cancer.

Another ingredient that exceeded the permissible standards is total organic carbon. An almost double increase in the amount of this component in the waters of the Święto Woda spring was recorded in both measurement series. The presence of organic carbon in water reservoirs causes deterioration of water quality. One of the sources of organic carbon is industrial waste. This ingredient can be highly toxic and persistent, accumulate in human bodies and cause adverse health effects [38].

Surface waters may be a carrier of pathogenic microorganisms when in contact with human feces. Microbiologically contaminated water becomes unsafe to drink. Escherichia coli is an excellent indicator of fecal water contamination. Microbiological analyzes showed that in both series the number of heterotrophic bacteria was 4 cfu/100ml in the first sample from the Dobro Woda source and 13 and 5 in the second source (number of Escherichia coli). It should be noted that a higher number of bacteria was found in samples from November. Their lower content or their complete absence was observed in samples from February, at lower temperatures.

WQI indices were also calculated for both measurement series. The index was calculated for six parameters, i.e. EC, pH, dissolved oxygen, nitrates, phosphates and the total number of microorganisms at 22±2°C. In the case of Dobro Woda spring, the index values were 99 and 108, respectively. And in the case of Święta Woda spring, this index reached 103 in November and 115 in February. According to the classification for this index, the values calculated in this way indicate high water pollution. In both cases, the high value of the WQI index was influenced by the number of microorganisms, which determined this value in 63% (Fig. 3, 4). Additionally, the dissolved oxygen value and the pH value had a significant influence.

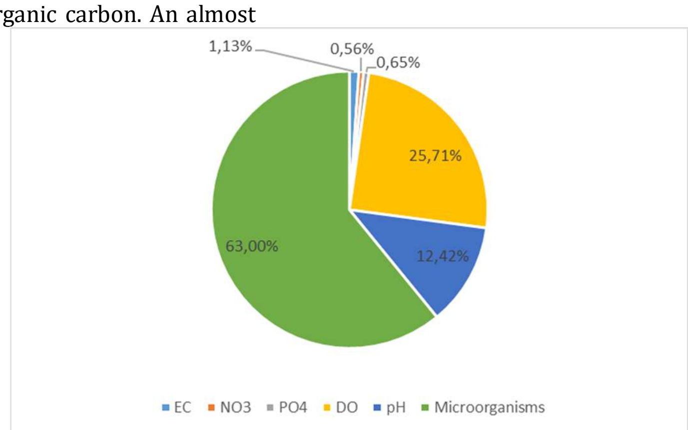

Fig. 4 Average percentage of individual parameters in the WQI value for Dobro Woda spring.

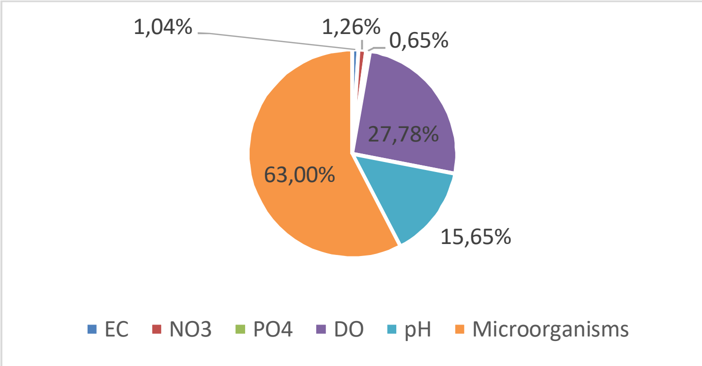

Fig. 5 Average percentage of individual parameters in the WQI value for Święto Woda spring.

Due to the fact that water from both sources is constantly drawn for drinking purposes by local residents and tourists, it is important to constantly monitor the variability of selected parameters. Unfortunately, such measurements are not carried out for most of these types of places, although such action would ideally fit into the concept of smart city - smart water [39]. At the outflow of springs in the Palowice Lake District, it would be possible to install sensors that would function in a sustainable Internet of Things (IoT) network of several sensors [40]. It should be noted that many people obtain information about the tourist and landscape values of places such as the described lake district from the Internet. Unfortunately, not everyone knows about water quality, changes in physicochemical and bacteriological parameters. Additionally, even people who use springs' water resources very often are not aware of the contamination content and possible health consequences. The ideal solution would be to use the capabilities of the Narrowband Internet of Things (NB-IoT), which is the licensed spectrum of standardized the low power wide area network. Combining the capabilities of mobile networks with the Internet of Things is popular because it allows reading data from various sensors, which can be placed even in hard-to-reach places. Sensors operating within the licensed cellular communications spectrum allow NB-IoT to improve range by 20 dB compared to GSM. Additionally, sensors operating in this way can operate on one battery for up to 15 years [41,42]. Sensor systems created in this way, operating within the selected operator's cellular networks, can send data to appropriate applications and can also be made available on the website. Such solutions have already been implemented to maintain rational water management by various cities in Poland and the T-Mobile mobile network, e.g. installation of an analytical buoy on the Odra River (https://www.wroclaw.pl/dla-mieszkanca/analityczna-bojka-zostala-launched-on-the-Oder-in-centre-of-Wroclaw).

In this way, people interested in the analyzed area and the possibility of obtaining water could receive information about the current quality of water and the lack of contraindications to drinking it. There are many urban facilities around the world facing similar challenges related to water, waste and climate change. The exchange of knowledge and experience between cities, i.e. the city to city (C2C) model, is becoming more and more popular. By introducing this form of social learning, it would be possible to achieve economic, environmental and health goals [43].

CONCLUSIONS

This study revealed some disturbing issues related to water use in urban areas. Samples from the Dobro Woda and Święto Woda springs contain increased concentrations of iron, manganese, nickel, TOC and bacteria, such as coliforms and enterococci. Each of these parameters means that these waters should not be consumed by humans without additional treatment. Additionally, the water is characterized by a reduced pH value and an increased dissolved oxygen value. The indicated parameters occurring in higher concentrations, in addition to affecting health, also cause negative economic effects, such as pipe corrosion. The high level of pollution in these waters is also confirmed by the high values of the WQI index (above 100), which is largely influenced by the content of microorganisms.

Due to the fact that the studied sources are located within an urban area used for tourism and recreation, it is extremely important in this context to constantly monitor changes in the quality of these waters. This can be achieved using modern technologies such as the Narrowband Internet of Things (NB-IoT). Thanks to this technology and the installation of sensors sending data to an appropriate server, local residents would be regularly informed about the possibility of drinking good quality water. The Palowice Lake District is not the only area in urban space that is influenced by anthropogenic factors. It is therefore worth considering the possibilities of knowledge transfer with other cities based on the city to city methodology. It is very important to consider appropriate protection of springs against excessive contamination.

REFERENCES

1. Tonne C, Linda A, Deepti A, Isabelle A, Kristine B, Maximilian B, Christa B, et al. Defining pathways to healthy sustainable urban development. Environment International 2021; 146:106236, DOI 10.1016/j.envint.2020.106236;
2. Donghwan K, Lee S. Analyzing the effects of Green View Index of neighborhood streets on walking time using Google Street View and deep learning. Landscape and Urban Planning 2021; 205:103920, DOI 10.1016/j.landurbplan.2020.103920;
3. Rainer G. Producing Nature for Tourism: A Political Ecology Angle. Annals of Tourism Research 2018; 71:62–63, DOI 10.1016/j.annals.2018.01.004;
4. Collins RM, Spake R, Brown KA, Ogutu BO, Smith D, Eigenbrod F. A Systematic Map of Research Exploring the Effect of Greenspace on Mental Health. Landscape and Urban Planning 2020; 201:103823, DOI 10.1016/j.landurbplan.2020.103823;
5. Zhicheng Z, Shen W, Li Y, Qin Y, Wang L. Spatial Equity of Park Green Space Using KD2SFCA and Web Map API: A Case Study of Zhengzhou, China. Applied Geography 2020; 123:102310, DOI 10.1016/j.apgeog.2020.102310;
6. Šourková M, Adamcová D, Zloch J, Skutnik Z, Vaverková MD. Evaluation of the Phytotoxicity of Leachate from a Municipal Solid Waste Landfill: The Case Study of Bukov Landfill. Environments 2020; 7(12):111, DOI 10.3390/environments7120111;
7. Al-Ghouti MA, Khan M, Nasser MS, Al-Saad K, Heng OE. Recent Advances and Applications of Municipal Solid Wastes Bottom and Fly Ashes: Insights into Sustainable Management and Conservation of Resources. Environmental Technology & Innovation 2021; 21:101267, DOI 10.1016/j.eti.2020.101267;
8. Abubakar IR, Maniruzzaman KM, Dano UL, AlShihri FS, AlShammari MS, Ahmed SMS, Al-Gehlani WA, Alrawaf TI. Environmental Sustainability Impacts of Solid Waste Management Practices in the Global South. International Journal of Environmental Research and Public Health 2020; 19(19):12717, DOI 10.3390/ijerph191912717;
9. Cirrincione L, Gennusa ML, Peri G, Rizzo G, Scaccianoce G. The Landfilling of Municipal Solid Waste and the Sustainability of the Related Transportation Activities. Sustainability 2022; 14(9):5272, DOI 10.3390/su14095272;
10. Owamah IH, Asiagwu AK, Egboh SHO, Phil-Usiayo S. Drinking Water Quality at Isoko North Communities of the Niger Delta Region, Nigeria. Toxicological & Environmental Chemistry 2013; 95(7): 1116–1128, DOI 10.1080/02772248.2013.847939;
11. McDonald RI, Weber K, Padowski J, Flörke M, Schneider C, Green PA, Gleeson T, et al. Water on an Urban Planet: Urbanization and the Reach of Urban Water Infrastructure. Global Environmental Change 2014; 27:96–105, DOI 10.1016/j.gloenvcha.2014.04.022;
12. Du L, Peng X, Zhao Y, Lyu J, Pan M. From Nature-Based to Engineering-Based: The Interaction Process and Turning Point of the City-Water System Relationship in the North China Plain. Applied Geography 2021; 135:102556, DOI 10.1016/j.apgeog.2021.102556;
13. Fitoka E, Tompoulidou M, Hatziiordanou L, Apostolakis A, Höfer R, Weise K, Ververis C. Water-related ecosystems' mapping and assessment based on remote sensing techniques and geospatial analysis: The SWOS national service case of the Greek Ramsar sites and their catchments. Remote Sensing of Environment 2020; 245:111795, DOI 10.1016/j.rse.2020.111795;
14. Backes JG, Traverso M. Life cycle sustainability assessment as a metrics towards SDGs agenda 2030. Current Opinion in Green and Sustainable Chemistry 2022; 38:100683, DOI 10.1016/j.cogsc.2022.100683;
15. Zhao Y, Wang Y, Wang Y. Comprehensive Evaluation and Influencing Factors of Urban Agglomeration Water Resources Carrying Capacity. Journal of Cleaner Production 2021; 288:125097, DOI 10.1016/j.jclepro.2020.125097;
16. Malakar K, Lu C. Measuring sustainability as distance to ideal position of economy, society and environment: Application to China's provincial water resources (2004–17). Journal of Environmental Management 2021; 292:112742, DOI 10.1016/j.jenvman.2021.112742;
17. Liu H, Xia J, Zou L, Huo R. Comprehensive quantitative evaluation of the water resource carrying capacity in Wuhan City based on the “human–water–city” framework: Past, present and future. Journal of Cleaner Production 2022; 366:132847, DOI 10.1016/j.jclepro.2022.132847;
18. Jokiel P. Springs, their role in the environment and importance in water management. Folia Geographica 1997; 2:5–7;
19. Sari MM, Andarani P, Notodarmojo S, Harryes RK, Nguyen MN, Yokota K, Inoue T. Plastic Pollution in the Surface Water in Jakarta, Indonesia. Marine Pollution Bulletin 2022; 182:114023, DOI 10.1016/j.marpolbul.2022.114023;
20. Keeler BL, Polasky S, Brauman KA, Johnson KA, Finlay JC, O'Neill A, Kovacs K, Dalzell B. Linking water quality and well-being for improved assessment and valuation of ecosystem services. Proceedings of the National Academy of Sciences 2012; 109(45):18619–18624, DOI 10.1073/pnas.1215991109;
21. Pokładek R, Kowalczyk T, Orzepowski W, Pulikowski K. Na, K, Ca and Mg concentrations in effluent water drained from agricultural catchment basins in Lower Silesia. Journal of Elementology 2011; 16(3):467-479, DOI 10.5601/jelem.2011.16.3.11;
22. Chen Z, Auler AS, Bakalowicz M, Drew D, Griger F, Hartmann J, Jiang G, et al. The World Karst Aquifer Mapping project: concept, mapping procedure and map of Europe. Hydrogeology Journal 2017; 25(3): 771–785, DOI 10.1007/s10040-016-1519-3;
23. Nitasha K, Tyagi S. Influences of Natural and Anthropogenic Factors on Surface and Groundwater Quality in Rural and Urban Areas. Frontiers in Life Science 2014; 8(1):23–39, DOI 10.1080/21553769.2014.933716;
24. Grimalt JO, Fernandez P, Berdie L, Vilanova RM, Catalan J, Psenner R, Hofer R, et al. Selective Trapping of Organochlorine Compounds in Mountain Lakes of Temperate Areas. Environmental Science & Technology 2001; 35(13):2690–2697, DOI 10.1021/es000278r;
25. Gothwal R, Shashidhar T. Antibiotic Pollution in the Environment: A Review. CLEAN – Soil, Air, Water 2014; 43(4):479–489, DOI 10.1002/clen.201300989;
26. Kumar R, Sharma P, Manna C, Jain M. Abundance, Interaction, Ingestion, Ecological Concerns, and Mitigation Policies of Microplastic Pollution in Riverine Ecosystem: A Review. Science of The Total Environment 2021; 782:146695, DOI 10.1016/j.scitotenv.2021.146695;
27. Muter O, Bartkevics V. Advanced analytical techniques based on high-resolution mass spectrometry for the detection of micropollutants and their toxicity in aquatic environments. Current Opinion in Environmental Science & Health 2020; 18:1–6, DOI 10.1016/j.coesh.2020.05.002;
28. Chartres N, Bero LA, Norris SL. A Review of Methods Used for Hazard Identification and Risk Assessment of Environmental Hazards. Environment International 2019; 123:231–239, DOI 10.1016/j.envint.2018.11.060;
29. Sumdang N, Chotpantarat S, Cho KH, Thanh NN. The risk assessment of arsenic contamination in the urbanized coastal aquifer of Rayong groundwater basin, Thailand using the machine learning approach. Ecotoxicology and Environmental Safety 2023; 253:114665, DOI 10.1016/j.ecoenv.2023.114665;
30. Chegbeleh LP, Akurugu BA, Yidana SM. Assessment of Groundwater Quality in the Talensi District, Northern Ghana. The Scientific World Journal 2020; 4:1–24, DOI 10.1155/2020/8450860;
31. Kondracki J. Geografia Regionalna Polski. Warszawa: Wydawnictwo Naukowe PWN; 2000;
32. Labus K. Chemistry and origin of mine waters in the southwestern part of Upper Silesia Coal Basin. Kraków: Wydawnictwo Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN; 2003;
33. Różkowski A. Map of the conditions of occurrence, use, threat and protection of ordinary underground waters of the Upper Silesian Coal Basin and its periphery; 1: 100,000. Warsaw: Polish Geological Institute; 1997;
34. Patel DD, Mehta DJ, Azamathulla HM, Shaikh MM, Jha S, Rathnayake U. Application of the Weighted Arithmetic Water Quality Index in Assessing Groundwater Quality: A Case Study of the South Gujarat Region. Water 2023; 15(19):3512, DOI 10.3390/w15193512;
35. Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda [Internet]. Geneva: World Health Organization 2022; PMID: 35417116;
36. Thelemann M, Bebermeier W, Hoelzmann P, Lehnhardt E. Bog iron ore as a resource for prehistoric iron production in Central Europe — A case study of the Widawa catchment area in eastern Silesia, Poland. CATENA 2017; 149:474–490, DOI 10.1016/j.catena.2016.04.002;
37. Bouchard M, Laforest F, Vandelac L, Bellinger D, Mergler D. Hair Manganese and Hyperactive Behaviors: Pilot Study of School-Age Children Exposed through Tap Water. Environmental Health Perspectives 2007; 115(1):122–27, DOI 10.1289/ehp.9504;
38. Bisutti I, Hilke I, Raessler M. Determination of Total Organic Carbon – an Overview of Current Methods. TrAC Trends in Analytical Chemistry 2004; 23(10–11):716–26, DOI 10.1016/j.trac.2004.09.003;
39. Mukherjee S, Ashfaq M, Mishra AK. Compound Drought and Heatwaves at a Global Scale: The Role of Natural Climate Variability-Associated Synoptic Patterns and Land-Surface Energy Budget Anomalies. Journal of Geophysical Research: Atmospheres 2020; 125(11), DOI 10.1029/2019jd031943;

40. Satyam, Mukherjee P. Implications of Progressive Data Transfer Technologies for IOT-Based Wastewater Management in Smart Cities. Applications of 5G and Beyond in Smart Cities 2023; 129–142, DOI 10.1201/9781003227861-8;
41. Prados-Garzon J, Ameigeiras P, Ordonez-Lucena J, Munoz P, Adamuz-Hinojosa O, Camps-Mur D. 5G Non-Public Networks: Standardization, Architectures and Challenges. IEEE Access 2021; 9:153893–153908, DOI 10.1109/access.2021.3127482;
42. Hamidi-Sepehr F, Sajadieh M, Panteleev S, Islam T, Karls I, Chatterjee D, Ansari J. 5G URLLC: Evolution of High-Performance Wireless Networking for Industrial Automation. IEEE Communications Standards Magazine 2021; 5(2):132–40, DOI 10.1109/mcomstd.001.2000035;
43. Boer J, Dieperink C, Mukhtarov F. Social Learning in Multilevel Flood Risk Governance: Lessons from the Dutch Room for the River Program. Water 2019; 11(10):2032, DOI 10.3390/w11102032.

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