DOI 10.7343/as-2024-805

ACQUE SOTTERRANEE
Italian Journal of Groundwater
journal homepage: https://www.acquesotterranee.net/

Initiative of EuroGeoSurveys' Urban Geology and Water Resources Expert Groups
Special Issue:
Groundwater in the cities of Europe

Groundwater in Katowice - center of a large urban and deep coal mining area in Poland

Acque sotterranee a Katowice - centro di una vasta area urbana e di estrazione del carbone in profondità in Polonia

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ARTICLE INFO

Ricevuto/*Received*: 10 July 2024
Accettato/*Accepted*: 27 September 2024
Pubblicato online/*Published online*: 30 September 2024

Handling Editor:
Nico Dalla Libera

Citation:
Razowska-Jaworek, L. (2024). Groundwater in Katowice - center of a large urban and deep coal mining area in Poland Acque Sotterranee - *Italian Journal of Groundwater*, 13(3), 157 - 165
https://doi.org/10.7343/as-2024-805

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Keywords: *groundwater, urban area, coal mining -industrial area, public water intakes.*

Parole chiave: acque sotterannee, area urbana, area post-industriale di estrazione del carbone, derivazioni d'acqua potabile.

Riassunto

Il presente articolo descrive le risorse idriche sotterranee di Katowice e i risultati degli studi condotti per identificare porzioni di acquiferi con risorse idriche sufficienti per la localizzazione di prese pubbliche per l'acqua potabile. La città di Katowice è il capoluogo dell'Alta Slesia, la più grande area urbano-industriale della Polonia, una regione con un'industria estrattiva del carbone fortemente sviluppata e numerose altre industrie che coprono quasi l'intero ambito dell'economia. A causa del drenaggio indotto dalle miniere, il quale ha provocato l'esaurimento e il deterioramento delle risorse idriche sotterranee e superficiali, le principali prese d'acqua municipali sono state collocate al di fuori di Katowice. La maggior parte dell'acqua pompata dalle miniere viene scaricata nelle acque superficiali, causando un'elevata salinità dell'acqua e rendendola inadatta all'uso civile o industriale a Katowice. Il sistema di raccolta e distribuzione dell'acqua è molto esteso e copre una parte significativa dell'agglomerato urbano, motivo per cui Katowice è rifornita da prese d'acqua superficiali situate al di fuori della città. Secondo la letteratura pubblicata in passato, come ad esempio la Mappa Idrogeologica della Polonia, nella città non esistevano acquiferi che potessero essere utilizzati per fornire acqua potabile alla città; tuttavia, studi recenti hanno dimostrato che le acque sotterranee negli acquiferi quaternari localizzati nella parte occidentale della città possono essere utilizzate per l'approvvigionamento idrico pubblico. Gli acquiferi quaternari meno produttivi presenti nelle parti nord-orientali della città potrebbero, inoltre, costituire una base per l'approvvigionamento di acqua potabile in situazioni di emergenza, quando le prese d'acqua superficiali non possono essere utilizzate in caso di contaminazione chimica, radiologica, virale o di danni alla rete idrica, ad esempio come risultato di un terremoto o di un conflitto bellico.

Abstract

The paper presents the groundwater resources of Katowice and the results of studies conducted to identify prospective areas in aquifers with sufficient water resources for the location of public water intakes. The city of Katowice is the capital of Upper Silesia, the largest urban-industrial area in Poland, the region with a highly developed hard coal mining and many other different industries covering almost the entire scope of the economy. Due to long term drainage of mines causing the depletion and deterioration of groundwater and surface water resources, the main municipal water intakes have been located outside Katowice. Most of the pumped mine water is discharged into surface waters, causing significant salinity of water and disallow its use for municipal or industrial purposes in Katowice. The water collection and supply system is very extensive and covers a significant part of the Silesian agglomeration which is why Katowice is supplied with water from surface water intakes located outside the city. According to older published materials, such as the Hydrogeological map of Poland, there were no aquifers in the city that could have been used to supply the city with drinking water, however recent studies have shown that groundwater in the Quaternary aquifers in the western part of the city can be used to supply the city with public water. Less productive, Quaternary aquifers in north-eastern parts of the city may constitute the basis for drinking water supply in emergency situations, when surface intakes cannot be used, such as toxic, radiological or viral contamination or damage to the water supply network eg. as a result of an earthquake or warfare.

Introduction

Katowice is the capital of the Upper Silesian region, the largest urban-industrial area in Poland. The area of the city is 164.5 km^2, and the number of inhabitants is 280 000 (Dec. 2023). Katowice is the economic and administrative center of the region with a highly developed hard coal mining, machinery, metal, chemical and ceramic industry as well as food industry and many other production plants covering almost the entire scope of the economy. Katowice is a very important transport junction, both road and rail. For many years, due to mining and industrial activities, the main municipal water intakes have been located outside Katowice; the water collection and supply system is very extensive and, apart from the city of Katowice, covers a significant part of the Silesian agglomeration. As a result of mining activities, water conditions in the city area changed. The most important consequences were: reduction of groundwater resources, lowering of the water table in public and domestic wells, drying of shallow domestic wells, the disappearance of springs and surface streams, and the intensive infiltration of water from surface streams into the ground (Różkowski, Różkowski, 2011; Wilk ed., 2003). Currently, most of the pumped mine water is discharged into surface waters, causing significant salinity of water and disallow its use for municipal or industrial purposes, therefore, Katowice is supplied with water from surface water intakes located outside the city (Dziećkowice, Goczałkowice, Czaniec and Maczki). In 2023, the city was connected to 99% of the water supply network. The reason of high salinity of discharged water is mine drainage of deep saline Carboniferous aquifers (from depth up to 1000 m). The salinity of water of these aquifers is caused by the marine origin of these waters (Pałys, 1971).

Over the 70 years many hydrogeological studies have been conducted in Katowice, but most of them were aimed at recognizing the hydrogeological conditions for hard coal mines and mine drainage (Jackowicz-Korczyński, 1996; Różkowski and Chmura eds., 1996; Różkowski, Chmura, Siemiński eds., 1997; Wilk, ed., 2003; Pluta, 2005). Those projects led to a good exploration of aquifers, especially in the Carboniferous sediments. Almost all studies were conducted during intense groundwater drainage by the mines and the aquifers in this area were considered unsuitable for public water supply (Różkowski et al, 1997a) mainly due to a significant lowering of water level and a reduction of groundwater resources .

The Hydrogeological Map of Poland at a scale 1:50 000 (Wagner & Chmura, 1997; Chmura & Wagner, 1997) as well as the hydrogeological map of the Upper Silesian Coal Basin (Ró-żkowski et al, 1997a) and monographs (Jackowicz-Korczyński, 1996; Różowski et al., 1997b) were prepared in the late 1990s, when the process of closure of coal mines just began, therefore most of the Katowice area is presented on these maps as areas without aquifers suitable for public water supply.

Therefore, in addition to describing the aquifers occurring within the city limits, the article presents their importance for the population of the city of Katowice.

Works carried out over the last 20 years (Nowak et al., 2015; Razowska-Jaworek et al., 2005; Razowska-Jaworek, 2007; Razowska-Jaworek et al., 2018) began to indicate the possibility of using groundwater from the Quaternary aquifers located within the city limits

Materials and Methods

The detailed hydrogeological study was conducted to recognize groundwater resources in Katowice. Firstly, all available hydrogeological papers and maps describing hydrogeological conditions in the Katowice area were collected and analyzed, such as Hydrogeological Map of Poland at a scale 1: 50 000 Katowice sheet (Wagner, Chmura, 1997) and Zabrze sheet (Chmura, Wagner, 1997) as well as hydrogeological projects: national (Paczyński & Sadurski eds., 2007), regional (Pluta, 2005; Różkowski et al., ed, 1997b) and many local geotechnical projects, mining, hydrogeological and geological documents. Geological, hydrogeological and mining datasets were also analyzed in order to collect all the data of the aquifers (Razowska-Jaworek et al, 2005; Razowska-Jaworek, 2018). The results of groundwater monitoring networks: national, regional and local were also taken into account. The information concerning regional and local monitoring networks and water usage in the city was collected in the Katowice Municipal Office and Upper Silesian Waterworks.

All geological and hydrogeological data located within Katowice limits have been collected in one database. This database includes the location, depth, thickness, lithology of geological formations and hydrogeological data such as: the presence of aquifers, deep wells, domestic shallow wells, conductivity, discharge, thickness of aquifers, etc. Based on this data and existing geological maps and cross-sections a hydrogeological map of the city was prepared. In addition to the data described above, information on land use and mining activities was collected. As a result, the geological structure, hydrogeological conditions, threats to groundwater and water use were identified, which are described in the paper.

The city area is located within the Silesian-Kraków Upland. There are various forms of land use in the Katowice area. Despite the industrial character of the city, the 41.7% of its area, is covered by forests located in the southern part of the city (Fig. 1). Residential development areas cover 29.5% and occupy the central part of the city and extensive areas outside the center, large housing estates. A significant part of the city's area (10.8%) are communication areas. Almost all the most important international and national roads in the Upper Silesian region intersect in Katowice.

The climate is dominated by oceanic influences over continental. The average annual temperature is 7.9 oC, and the average annual rainfall ranges from 731 to 855 mm.

The city is located in the first-order surface water divide between the Oder and Vistula river basins (Fig. 1). The Oder river basin covers the central-western part of the city, drained by the Kłodnica with Ślepiotka Rivers. The northern part of the city is drained by the Rawa, Brynica and Mleczna Rivers

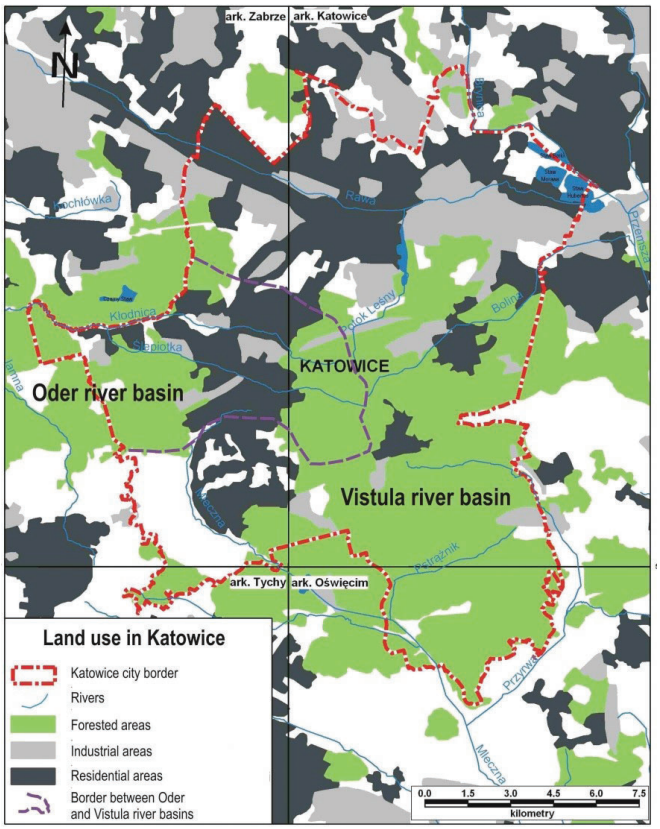

Fig. 1 - Land use and surface waters in Katowice city (after Chmura et al., 2011, modified).

Fig. 1 - Mappa dell'uso del suolo e del reticolo idrografico superficiale nella città di Katawice (ripreso e modificato da Chmura et al., 2011)

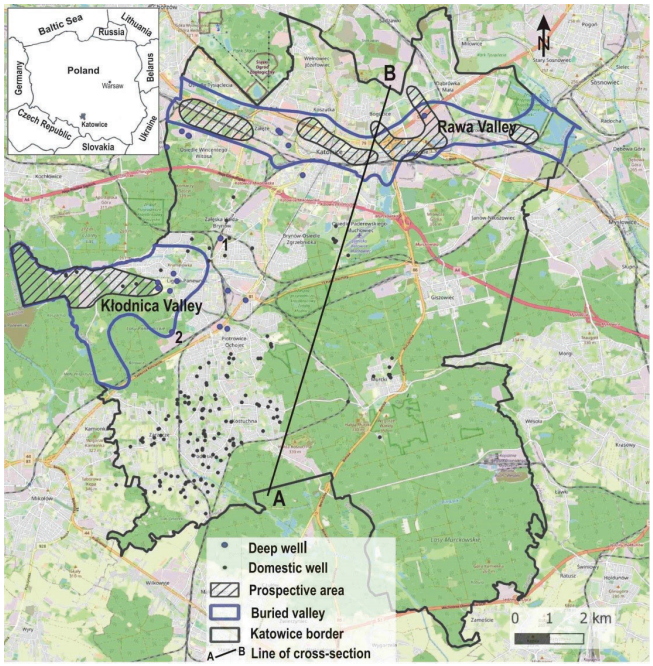

Fig. 2 - Map of Katowice city with the prospective areas (after Razowska-Jaworek et al., 2018).

Fig. 2 - Carta della città di Katowice con le potenziali aree sfruttabili (ripreso da Razowska-Jaworek et al., 2018)

belonging to the Vistula river basin. Within the city limits there are springs of two rivers: Kłodnica and Ślepiotka as well as several dozen artificial water reservoirs, mostly flooded sand and clay pits or subsidence basins (Fig. 2).

Geology

Katowice is located in the Upper Silesian Coal Basin. The basement is composed of Paleozoic rocks: shales, sandstones and conglomerates with coal seams belonging to the Upper Carboniferous (Wilanowski et al, 2009; Wilanowski, 2016). Their outcrops occur over a large area of the city. The Carboniferous "Upper Silesian Sandstone Series" is composed of various-grained sandstones and conglomerates with interlayers of mudstones and clayly shales, among which there are, or rather were, coal seams (Fig. 3). The "Mudstone Series" is dominated by clayly shales with coal seams. The most widespread are the Orzeskie Beds, a huge series of shales with interbedded sandstones, siderites and over 50 coal seams, two of which are over 1.5 m thick. The Carboniferous formations dip monoclinally towards the south with a variable angle of inclination and are cut by numerous faults (Wagner, 1998).

Triassic carbonate deposits: limestones, dolomites and marls lie on the Carboniferous formations in the western and southern parts of the city. The thickness of this formations in this area is variable and ranges from 57 m to 125 m in the southern part of the city. The tectonic depressions are filled with the Miocene clays and sands with a thickness of several dozen meters, reaching in the Kłodnica Valley 120 m.

The Quaternary is represented by sands, gravels and clays of the Pleistocene and Holocene age. The thickness of these sediments is variable, ranging from less than 1 meter to 100 m in the Kłodnica valley. Modern river valleys, filled with Holocene sediments are several meters thick, and are composed of sands, gravels, silts and clays.

The original surface of Katowice has been transformed as a result of human activity. The exploitation of raw materials, waste storage, industrial development, expansion of cities and communication infrastructure, which has been ongoing for over two centuries, have resulted in permanent changes in the geological structure and geomorphology of the city (Kupka et al, 2010). Numerous anthropogenic forms appeared such as: clay pits, sand pits, coal dumps and metallurgical plants, coal sludge settling tanks, various embankments and excavations related to communication lines. Hard coal mining caused irreversible changes in the rock mass (Wilk ed., 2003). There are 12 mining areas in the city, including 2 active coal mines and 5 closed coal mines.

Hydrogeology

The Katowice area is located in the Upper Oder and small Vistula hydrogeological regions (Paczyński & Sadurski, 2007). The Quaternary, Neogene, Triassic and Carboniferous aquifers were identified in this area (Fig. 4).

The Quaternary aquifer does not form a continuous cover and is associated with sand-gravel and sand-silty inter-moraine, fluvial-glacial and river deposits (Razowska-Jaworek, 2007). Significant aquifers occur in the Kłodnica, Rawa and Mleczna

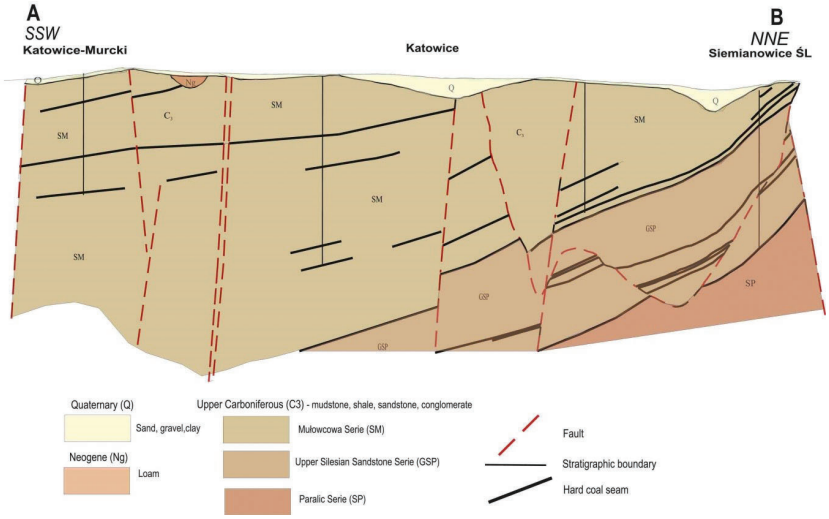

Fig. 3 - Schematic geological cross-section A-B (after Razowska-Jaworek, 2007).
Fig. 3 - Sezione geologica lungo il profilo A-B (ripreso da Razowska-Jaworek, 2007).

valleys (Fig. 4). These valleys are generally composed of two aquifers: shallow with a depth up to 5 m, used by domestic wells (mainly for watering of gardens) and deeper, confined, at a depth of 20-60 m (Fig. 2). The discharge of wells range from a few to 100 m^3/h, with an average of 10-20 m^3/h (Table 1).

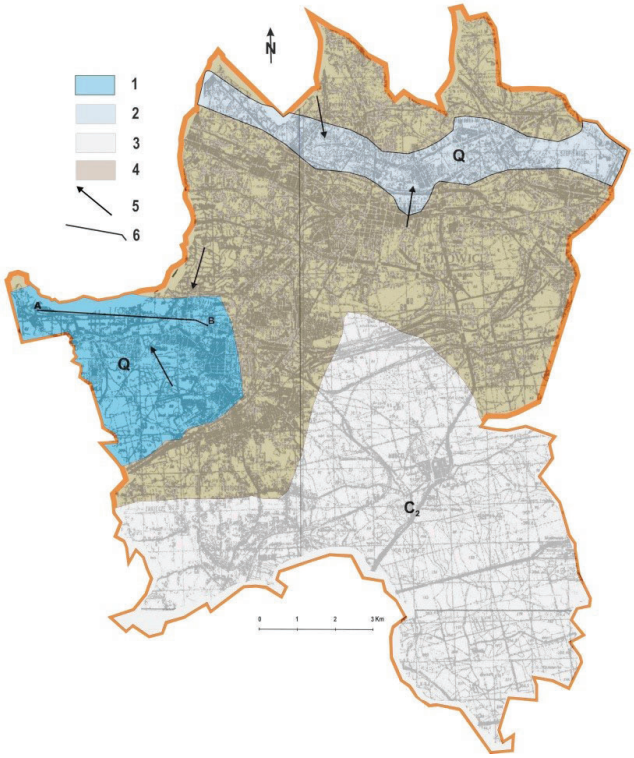

Fig. 4 - Hydrogeological map of the Katowice area. 1–highly productive porous aquifer of Kłodnica river valley, 2-moderate productive porous aquifer of Rawa river valley, 3-local and limited groundwater, 4-area without aquifers suitable for public water supply, 5-groundwater flow direction, 6-line of the cross-section, Q – Quaternary aquifers, C – Carboniferous aquifer.

Fig. 4 - Mappa idrogeologica dell'area di Katowice. 1- Acquifero poroso ad elevata produttività della valle del fiume Kłodnica, 2 – Acquifero poroso a media produttività della valle del fiume Rawa, 3 – Acquiferi localmente limitati, 4 – Aree con acquiferi non utilizzabili per l'estrazione di acqua potabile, 5 – Direzione di deflusso delle acque sotterranee, 6 – profilo A-B della sezione geologica, Q – Acquiferi Quaternari, C – Acquiferi del Carbonifero.

Aquifers in the Neogene formations, which are generally impermeable formations, are associated with inserts of sandstones, sands and gravels. The thickness of the sandy inserts doesn't exceed 10 m and there are no wells collecting water from this aquifer.

The Triassic aquifer is associated with limestones and dolomitic marls occurring in small patches in the northern and south-eastern parts of the city (Firlit et al., 2015). This is a karst-fissured aquifer and show significant variations in the conductivity (6·10-5 - 3·10-4 m/s). Currently, there are no wells in Katowice that use waters from the Triassic aquifer

The Carboniferous aquifer occurs throughout the entire city area. The characteristics presented below concern the hydrogeological conditions of the area, but it should be borne in mind that currently this area is completely under the influence of mine drainage, which causes significant changes in the natural hydrogeological conditions (Wagner, 1998; Pluta, 2005).

In most parts of the city, Carboniferous deposits are found directly on the surface or under Quaternary or Triassic deposits so these aquifers are recharged here on outcrops or through the overburden. The areas of natural drainage are river valleys, and the areas of artificial drainage are coal mine workings.

In the Carboniferous profile, four separate hydrogeological complexes identified with lithostratigraphic series are distinguished (Wagner, 1998; Różkowski et al., 1997b): the aquifer complex in the Krakow Sandstone Series, the aquifer complex in the Upper Silesian Sandstone Series, which are divided by a Mudstone Series, which is characterized by low permeability (Fig. 3). The marginal layers forming the Paralic Series underlying the Upper Silesian Sandstone series also have low permeability. All Carboniferous aquifer complexes in this region contain separate, fractured and porous levels of sandstones and conglomerates, isolated by intercalations of impermeable shales and mudstones.

Mining operations are accompanied by collapses, cracks and relaxation of the rock mass, which increase the permeability of rocks and connect various aquifers as a result of interrupting the continuity of insulating layers (Rogoż & Posyłek, 2000).

Tab. 1 - Aquifers within Katowice borders.

Tab. 1 - Acquiferi presenti all'interno dei limiti della città di Katowice.

Aquifer	Lithology	Thickness [m]	Conductivity - k Discharge - Q
Quaternary	sands, gravels of fluvial-glacial and river origin	2÷30	$k=10^{-5}\div10^{-3}$ m/s; $Q=10\div20$ m^3/h
Triassic	karstic-fissured dolomites and limestones	20÷50	$k=10^{-5}\div10^{-4}$ m/s; $Q=10\div30$ m^3/h
Carboniferous	sandstones, conglomerates of stratigraphic series: Mudstone, Upper Silesian Sandstone, Paralic with fresh water tp the depth of 300 m	2÷60	$k=10^{-6}\div10^{-7}$ m/s; $Q=1,8\div48$ m^3/h

Long term drainage of water related to extraction activities has led to disruption of natural hydrogeological conditions such as lowering of the water table at the base of the "Upper Silesian Sandstone Series" (Różkowski and Różowski, 2011).

Due to the main role of Quaternary aquifers in the Katowice area, the city can be included in the category of Alluvial groundwater cities (AGC) category (La Vigna, 2022).

Quality of groundwater

The waters of the Quaternary aquifer are fresh or slightly mineralized, slightly alkaline, medium-hard and hard (Razowska-Jaworek et al, 2018). Due to higher iron and manganese content the use of these waters is possible after simple treatment. Table 2 presents the average values of selected quality parametres.

The characteristics of the water quality of the Carboniferous aquifer were based on physico-chemical analyzes of water collected mainly from mine intakes. In the discussed waters, the process of their pollution is very visible, leading to an increase in the content of sulfates and chlorides. These waters definitely require treatment. The results of chemical analyzes confirm significant physicochemical variability of the waters of the aquifers in Katowice area. In the shallow levels of the aquifers the water quality depends on the location of the well, in highly urbanized areas the content of nitrate reached 80 mg/L and ammonia 2 mg/L (Razowska-Jaworek et al, 2018).

Tab. 2 - Quality of fresh groundwaters in Katowice (after Razowska-Jaworek et. al, 2018).

Tab. 2 - Qualità degli acquiferi nella città di Katowice (ripreso da Razowska-Jaworek et. al, 2018).

Aquifer	Quaternary – shallow level	Quaternary – deeper level	Carboniferous – shallow level
No of samples	9	13	9
TDS (mg/L)	183 - 2106	203 – 1006	267 - 2000
pH	5.7 – 7.4	5.9 – 7.8	5.1 - 8.1
Sulfates (mg/L)	57.0 – 375.0	9 - 378	40.2 - 782.0
Chlorides (mg/L)	14.0 - 539.0	4.0 – 143.0	40.3 - 237.0
Nitrates (mg/L)	0 - 80	0 – 17.7	No data
Iron (mg/L)	0.04 – 15.22	0.02 – 5.00	0.02 – 0.05
Manganese (mg/L)	0.01 – 0.44	0.03 – 1.39	0.003 - 0.226

Results

The study of recent documentations and projects including Katowice city area led to the recognition of groundwater usage and hazards in Katowice, as well as the importance of the aquifers within Katowice borders for water supply of the city population.

In the past, several groundwater intakes were built in the city, mainly for industrial purposes. Deep wells, concentrated mainly in two valleys: Kłodnica and Rawa, exploited resources from the Quaternary and Triassic aquifers. Currently, almost all deep wells in the city are closed (Razowska-Jaworek & Wagner, 2005), only 2 wells were operating here in small industrial plants in 2023 year, abstracting the Quaternary aquifer with daily water production of 17.1 m^3 (well 1) and 8.8 m^3 (well 2) (Fig. 2).

Hard coal mines, from the beginning of mining activity, have been the main centers of groundwater drainage in the Upper Silesian Coal Basin, the basis of drainage are active or closed mine workings. Water drained from the rock mass and flowing into mining workings flows to drainage pumping stations located at the main shafts, generally in the deepest mining workings of mines. Mine water is used for technological needs in individual mines. Water flowing into and contained in mine workings is usually characterized by a variable inflow over time, variable quantity and unstable quality.

The environmental impact of mining and industry on groundwater resources

The main environmental threats in the city result from different activities: heavy industry, mining, urban. Most of the Katowice area is at risk of land subsidence caused by coal mining. Approximately 17% of the city's area is currently affected by land subsidence. There are several floodplain areas in the eastern and central parts of Katowice. The source of indirect threats from mining are rock mass tremors, i.e. rock bursts, which may contribute to damage to environmental protection infrastructure, including water supply and sewage networks.

The industrial plants currently having the greatest impact on the environment in Katowice include: two hard coal mines of the "Polish Mining Group" and four closed and abandoned mines:, where water is pumped to protect neighboring active mines.

The current main hydrogeological problems related to the mining, urban and post-industrial character of the city are presented in Table 3.

Discussion

Prospective areas for water supply

In the area of Katowice the main aquifers siutable for public water supply (Wagner & Chmura, 1997; Chmura & Wagner, 1997) occur in the Quaternary formation. Groundwater in the Quaternary aquifers occur in most parts of the city at a depth of less than 5 m, locally up to 60 m, but their distribution is discontinuous. Usually, these aquifers are isolated from the land surface by clays and silts. Two valleys are of greater hydrogeological importance: the Kłodnica River valley and the Rawa River valley (Figs. 2 and 4).

The western part of the city is located within one of the Major Groundwater Basins (MGB) in Poland (No. 331) of the Kłodnica River buried valley (Nowak et al, 2015). The thickness of this aquifer varies between 4.8 and 40.0 m, and the average depth of intakes in the entire reservoir is approximately 60 m. Single deep wells (outside Katowice borders, but very close) have an average productivity of 69 m^3/h, and the resources of the whole reservoir are estimated at 17 200 m^3/d. The aquifer collects fresh water with a TDS of less than 800 mg/L. Within this MGB, a prospective area for public water supply intake location has been proposed (Razowska-Jaworek et al., 2005; Razowska-Jaworek, 2007, 2016) (Fig. 2).

The total resources of the aquifer in the Kłodnica valley (Chmura & Wagner, 1997) were estimated at 270 m^3/d per km^2, therefore within the Katowice city limits the estimated resources of the prospective area are about 1,000 m^3/d.

This basin could provide drinking water supply for the

Tab. 3 - Environmental impact of main factors on groundwater in Katowice area.

Tab. 3 - Principali fattori che determina l'impatto ambientale nelle acque sotterranee dell'area di Katowice.

Activity	Environmental impacts on groundwater
Active Mining	–artificial recharge from water and waste water networks (losses), leaks caused by ground movement, –recharge from rivers –artificial lakes and lagoons formed by flooding of subsidence basins, –lowering of water pressure – cone of depression caused by mine drainage –depletion of water resources –drying of shallow, domestic wells –water contamination of shallow aquifers from mine dumps –no groundwater intakes
Abandoned mines	–since water is still pumped from all closed mines, the effects are similar to those in active mines –flooding the workings of a closed mine to the level of the lowest connection with neighboring mines does not significantly reduce the depression cone
Post-industrial	–water contamination from abandoned industrial activities –storm waters due to the impermeable concrete surfaces and huge buildings –water contamination from industrial waste storage –limited pumping of groundwater by industry – rising of water levels (flooding of basements or pipelines)
Urban	–water contamination near landfills, –exploitation of groundwater by many private wells (sometimes illegal), often inadequately sited –decrease of recharge due to impermeable compact land development, asphalt or concrete surfaces and roads –decrease of recharge due to higher temperatures in urban areas and evaporation rates –artificial recharge due to watering in the residential areas and parks

western part of the city, in a less urbanized area (Fig. 5). Prospective areas in the Rawa valley may also be taken into account, but, due to worse aquifer parameters, they could only be considered prospective emergency water supply. Especially, since the Rawa valley runs from west to east through the most urbanized parts of the city. Water production of single well ranges from several m^3/h to 30 m^3/h (Razowska-Jaworek et al., 2005).

No prospective areas have been identified within the Carboniferous aquifer, but water pumped from hard coal mines located within the city may potentially constitute an emergency source of water supply to the population in emergency situations, as on approximately 35% of the city area the Carboniferous aquifer meets the conditions for drinking water. It occurs in the southern part of Katowice, the thickness of the aquifer varies from 50 to 180 m and the aquifer is drained by the "Murcki" abandoned coal mine. The depth of waters suitable for drinking water supply is determined by the recorded inflows of these waters into mine workings at a depth of 60-420 m. The average resources are estimated at 190 $m^3/24h$ per km^2 (Wagner & Chmura, 1997).

Water flowing into the remaining mines cannot be used for drinking purposes due to high salinity. The water flowing into the workings of the "Murcki" mine has parameters qualifying it as drinking water and can be used after prior treatment.

The recent partial or total closure of mines in the Katowice and flooding the mine workings of a closed mine to the level of the lowest connection with neighboring mines has not significantly reduced a zone of lowered piezometric pressure (depression cone) formed as a result of mine drainage. Neighboring active mines take over the inflows to the closed mines, and some of the water flows into the Carboniferous aquifers, increasing their water resources.

However, in the future, it is planned to close all the mines in Katowice area and flood them to a safe level.

The most important problem when closing mines is the deterioration of water quality in flooded mine workings. These waters are usually characterized by high content of sulfates and metals and very often a low pH (AMD – Acid Mine Drainage). They may remain in the area of flooded mine workings for several hundred years, and purification of these waters without human involvement is not possible (Razowska, 2001).

Therefore, when analyzing the possibility of using mine waters as a source of drinking water, the method of closing the mine should be taken into account. If it is planned to flood all mine workings, the water collected in the flooded workings should not be planned to be used as a source of drinking water, but rather for other purposes , such as ATES (aquifer temporary energy storage) or use in geothermal power plants.

Conclusions

Aquifers occur in all stratigraphic formations located in Katowice city area, but their resources and water quality depend not only on natural factors, such as the properties of aquifers and their lithology, but also on anthropogenic factors, i.e. the impact of mining activities and the degree of urbanization and industrialization of Katowice city area.

Therefore, although aquifers within the city borders occur in the Quaternary, Neogene, Triassic and Carboniferous strata, most of the city area lacks aquifers which may be used for water supply to the population of Katowice.

In the western part of the city, in the buried valley of the Kłodnica River, the Quaternary aquifer of greater importance and can be considered as a source of public water supply .

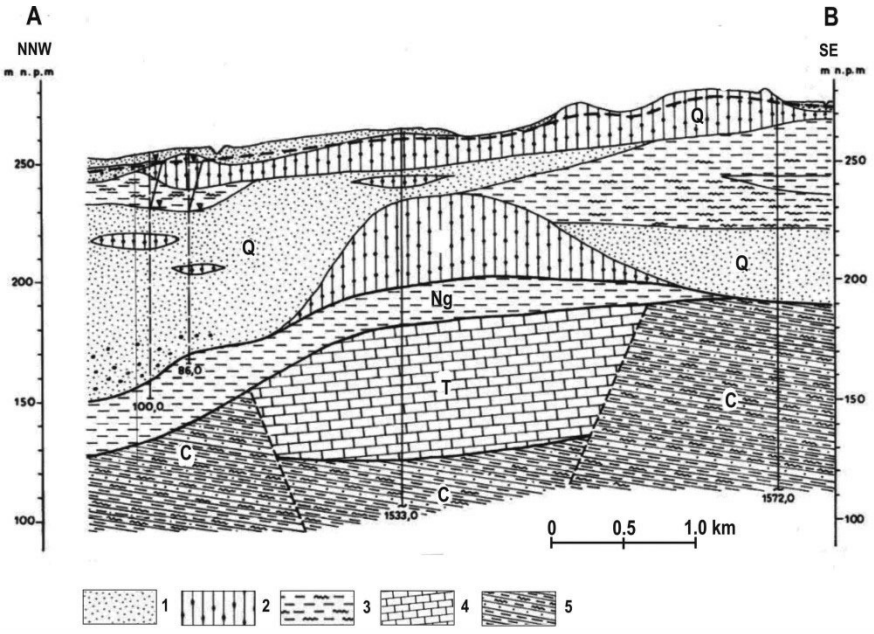

Fig. 5 - Hydrogeological cross-section of the prospective area in Kłodnica basin (after Razowska-Jaworek, 2007, modified). 1-sand and gravel, 2-clay, 3-loam, 4-limestone, 5-claystone, mudstone and sandstone, Q- quaternary, Ng – Neogene, C-Carboniferous.

Fig. 5 - Sezione idrogeologica dell'area potenzialmente sfruttabile nel bacino di Kłodnica (ripresa e modificato da Razowska-Jaworek, 2007). 1 – Ghiaie e sabbie, 2 – Argilla, 3 – Suolo franco, 4 – Calcare, 5 – Argillite, siltite e arenaria, Q – Quaternario, Ng – Neogene, C – Carbonifero.

The Quaternary aquifer in the Rawa river valley can only be considered as an emergency source of water for the population.

The Carboniferous aquifer is entirely impacted by mine drainage. Quantitative instability and variability of quality of water from this aquifer disqualifies it as a permanent source of drinking water. Groundwater pumped by mines from Carboniferous aquifer can serve as a source of drinking water for city in extreme situations and only after prior treatment. Despite the presence of active and inactive hard coal mines in the Katowice, entities responsible for water management could consider locating the citiy's own groundwater intake for public water supply.

Competing interest

The authors declare no competing interests.

Additional information

DOI: https://doi.org/10.7343/as-2024-805

REFERENCES

Chmura, A., Jureczka, J., Krieger, W., Ługiewicz-Mołas, I., Piotrowski, A., Sikora, R., Stachura, A., Szulik, J., Wilanowski, S. (2011) Rejestr zawierający informacje o zagrożeniach powierzchni ziemi na obszarze Katowic. *"Register containing information on threats to the earth's surface in Katowice"*. Archive Katowice City Office.

Chmura, A., Wagner, J. (1997) Mapa hydrogeologiczna Polski. Skala 1:50 000. Hydrogeological map of Poland at a scale 1:50 000. Sheet Zabrze. https://baza.pgi.gov.pl/resources.html?type=map50&id=942

Firlit, G., et. al. (2015) Dokumentacja hydrogeologiczna określająca warunki hydrogeologiczne w związku z ustanawianiem obszarów ochronnych Głównego Zbiornika Wód Podziemnych nr 329 Bytom. *"Hydrogeological documentation specifying hydrogeological conditions for the delimitation of protective areas of the Major Groundwater Basin No. 329"*. Bytom. Unpublished. Archive of PROXIMA S.A. Wrocław.

Jackowicz-Korczyński, J. (1996) Studium uwarunkowań hydrogeologicznych dla potrzeb zagospodarowania przestrzennego miasta Katowice. Biuro Rozwoju Miasta Katowice. *"Study of hydrogeological conditions for the spatial development of the city of Katowice"*. Unpublished. Archive. Katowice City Development Office.

Kupka, R., Pełka-Gościniak, J., Szczypek, T. (2010) Nature protection in the area of industrial city (a case study of Katowice). Anthropogenic aspects of landscape transformations. 6: 52-56.

La Vigna, F. (2022). Review: Urban groundwater issues and resource management, and their roles in the resilience of cities. Hydrogeol J 30, 1657–1683. https://doi.org/10.1007/s10040-022-02517-1

Nowak, R., Piotrowska, K., Dobrzański, P., Sobczak, A., Szymańczuk, J. (2015) Dokumentacja hydrogeologiczna określająca warunki hydrogeologiczne w związku z ustanawianiem obszarów ochronnych Głównego Zbiornika Wód Podziemnych nr 331 Dolina kopalna rzeki Górna Kłodnica. *"Hydrogeological documentation specifying hydrogeological conditions for the delimitation of protective areas of the Major Groundwater Basin No 331 Upper Kłodnica river buried valley"*. Unpublished. Archive. PROXIMA Wrocław

Paczyński, B., Sadurski, A., (red.). (2007) Hydrogeologia regionalna Polski. Regional hydrogeology of Poland. PGI. Warsaw.

Pałys, J. (1971). Pochodzenie słonych wód w karbonie ważniejszych zagłębi węglowych Europy na tle ich geologicznego rozwoju. *"The origin of salt waters in the Carboniferous of the major Ruropean coal basins in relation to their geological development"*. Wydawnictwa Geologiczne. Warsaw. 66.

Pluta, I., (2005) Wody kopalniane w Górnośląskim Zagłębiu Węglowym – pochodzenie, zanieczyszczenie i metody oczyszczania. *"Mine waters in the Upper Silesian Coal Basin – origin, pollution and treatment"*. Scientific Work of CMI no. 865. 169.

Razowska, L. (2001) Changes of ground water chemistry caused by the flooding of iron mines (Czestochowa Region, Southern Poland). Journal of Hydrology. 244:17–32

Razowska-Jaworek L. (2007). Wody podziemne w Katowicach. Groundwaters in Katowice in: Nowicki Z., ed. Wody podziemne miast wojewódzkich w Polsce. Groundwaters in capital cities of the regions in Poland. PGI. Warsaw. 41-54.

Razowska-Jaworek, L., Chmura, A., Wagner, J., Wilanowski, S. (2005) Inwentaryzacja studni gospodarczych i ujęć wód podziemnych na terenie miasta Katowice. *"Collecting data on wells and groundwater intakes in the city of Katowice and creating a database"*. Unpublished. Archive Katowice City Office.

Razowska-Jaworek, L. (2016) Emergency water supply for the population from groundwaters in the Upper Silesia (Poland). Groundwater and society: 60 years of IAH. 43rd International Association of Hydrogeologists Congress. Book of Abstracts. Montpelier. France. 910.

Razowska-Jaworek, L., Cudak, J., Karpiński, M., Pasternak, M. (2018) Aktualizacja inwentaryzacji studni gospodarczych i ujęć wód podziemnych na terenie miasta Katowice. *"Updating the database of wells and groundwater intakes in the city of Katowice"*. Unpublished. Archive. Katowice City Office.

Rogoż M., Posyłek E. (2000) Problemy hydrogeologiczne w polskich kopalniach węgla kamiennego. *"Hydrogeological problems in Polish coal mines"*. CMI. Katowice.

Różkowski A, Siemiński A, Rudzińska-Zapaśnik T., eds. (1997) Mapa warunków występowania, użytkowania, zagrożenia i ochrony wód podziemnych Górnośląskiego Zagłębia Węglowego i jego obrzeżenia. *"Map of the occurrence, use, threat and protection of groundwater in the Upper Silesian Coal Basin and its margins"*. PIG Warsaw.

Różkowski A., Chmura A., Siemiński A. eds. (1997) Użytkowe wody podziemne Górnośląskiego Zagłębia Węglowego i jego obrzeżenia. *"Usable groundwaters in the Upper Silesian Coal Basin and its margins"*. Prace PIG 159.

Różkowski A., Różkowski K. (2011) Wpływ działalności górnictwa węgla na kształtowanie się środowiska wodnego Górnośląskiego Zagłębia Węglowego w wieloleciu. *"Long term impact of coal mining on the environment in the Upper Silesian Coal Basin"*. Bulletin PGI. 445. 583-592.

Wagner J. (1998) Charakterystyka hydrogeologiczna karbonu produktywnego niecki głównej Górnośląskiego Zagłębia Węglowego. *"Hydrogeology of the Carboniferous productive aquifer in the main trough of the Upper Silesian Coal Basin"*. Bulletin PGI. 383.55-93

Wagner J., Chmura A. (1997). Mapa hydrogeologiczna Polski. Skala 1:50 000. *"Hydrogeologi-cal map of Poland at a scale 1:50 000"*. Katowice sheet. https://baza.pgi.gov.pl/resources.html?type=map50&id=943

Wilanowski S., Krieger W., Żaba M. (2009) Szczegółowa mapa geologiczna Polski. Skala 1:50 000. *"Geological map of Poland at a scale 1:50 000"*. Zabrze sheet. https://baza.pgi.gov.pl/resources.html?type=map50&id=942

Wilanowski S. (2016) Szczegółowa mapa geologiczna Polski. Skala 1:50 000. *"Geological map of Poland at a scale 1:50 000"*. Katowice sheet. https://baza.pgi.gov.pl/resources.html?type=map50&id=943

Wilk Z. ed. (2003) Hydrogeologia polskich złóż kopalin i problemy wodne górnictwa. *"Hydro-geology of Polish mineral deposits and water problems of mining"*. UWN-D. AGH. Kraków. 1. 611.

Zaleska M., Bieroński J., Kempski G., Panek D., Wojciechowicz D., Bajcar D., Wcisło M., Szyszkowska B., Szyszkowski P. (2004). Dokumentacja zasobów dyspozycyjnych wód podziemnych w zlewni Kłodnicy. *"Documentation of available resources of aquifers in Kłodnica Basin"*. Unpublished. Archive. ARCADIS Ekokonrem. Wrocław.