CONTENTS

INTRODUCTION

The 1:25,000 geochemical mapping in the Chorzów map sheet M-34-62-B-b is a continuation of the detailed mapping project that commenced in 1996–1999 with the pilot map sheet of Sławków M-34-63-B-b of the Detailed Geochemical Map of Upper Silesia (Lis, Pasieczna, 1999). By 2016, 17 map sheets had been developed. The work was financed by the National Fund for Environmental Protection and Water Management.

The map sheet area occupies the central part of the Upper Silesian Industrial Region, which is the most heavily industrialized and urbanized area of Poland, predominantly within the limits of the cities of Chorzów and Świętochłowice. The eastern part of the map sheet area spans parts of Siemianowice Śląskie and Katowice, its western part – the quarters of Ruda Śląska, whereas a small area near the northern boundary belongs to the city of Bytom.

The main factors affecting the quality of natural environment are the historical and modern mining of hard coal, energy industry, and iron and zinc metallurgy. These industries, being developed most intensely in the mid-19th century, are responsible for the formation of geological-anthropogenic anomalies of a number of chemical elements in soils, aqueous sediments, and surface waters (Lis, Pasieczna, 1995a, b, 1997).

Most of the map sheet area is highly industrialized and anthropogenically altered. It hosts numerous industrial facilities of the mining, energy, metallurgy and chemistry industries.

The results of geochemical studies, presented on the map with a comprehensive explanatory text and data tables, show the current quality of soils, sediments and water in inland reservoires against the natural regional background and in relation to the legal regulations.

The information provided in this report can be useful in assessing local land use plans, making decisions concerning environmental constraints, giving water-legal permits, assessing groundwater hazards, and discharging duties imposed upon district governors by the Environmental Protection Law, i.e. conducting regular soil quality tests within the framework of state monitoring system.

The digital version of the atlas is available at https://www.mapgeochem.pgi.gov.pl

The following specialists participated in the preparation of this report:

- **A. Pasieczna** – concept and project proposal, supervision and coordination of research;
- **A. Biel, K. Karwacki, T. Kołecki, P. Kwecko, W. Markowski** – sample collection;

- T. Kołecki, W. Markowski, A. Pasieczna – databases;
- **I. Jaroń, D. Lech, A. Maksymowicz, E. Włodarczyk**– leadership and coordination of analytical works;
- **M. Cichorski, Z. Prasol** – mechanical preparation of samples for analyses;
- **M. Bellok, M. Białecka, M. Gembal, E. Maciołek** – chemical preparation of samples for analyses;
- **J. Gąsior, M. Janasz, M. Jaskólska, M. Stasiuk** – determination of organic carbon content;
- **M. Bellok, M. Białecka, M. Gembal, E. Kaława, E. Maciołek** – determination of pH;
- **E. Górecka, D. Karmasz, J. Retka** – determination of mercury content;
- **W. Bureć-Drewniak, I. Jaroń, J. Kucharzyk, M. Liszewska** – ICP-AES analyses; **I.A. Wysocka** –ICP-MS analyses;
- **M. Chada, A. Lewandowska, A. Stawicka, W. Wolski, M. Zdonek** – grain-size analyses;
- **A. Pasieczna** – statistical calculations;
- **T. Kołecki, W. Markowski, A. Pasieczna** – construction of geochemical maps;
- **W. Ogrodowczyk** – geological map compilation.

CHARACTERISTICS OF THE MAP AREA

Geographical and administrative setting. The Chorzów map sheet M-34-62-B-b encompasses the central part of the Katowice Upland within a lower-rank unit called the Bytom-Katowice Plateau that is crossed by a watershed between the Odra and Vistula rivers (Kondracki, 2000).

The study area is located in the central part of Silesian Voivodeship. It includes a number of quarters of the district cities of Chorzów, Świętochłowice, Ruda Śląska, Bytom, Siemianowice Śląskie and Katowice, which together form an urban-industrial agglomeration with Poland’s highest population density and industry concentration.

Relief and geomorphology. The map sheet area shows a diverse relief, locally highly altered as a result of industrial activity. The study area lies at elevations ranging from 250.0 to 338.8 m a.s.l. (in the Bytomka River valley and Kochłowice Hills, respectively).

The changes in natural environment have been caused by hard coal mining, iron and zinc metallurgy, and energy industry which contributed to the formation of piles of gaunge and smelting slags, as well as other wastes stored in the immediate proximity to mines, smelters and residential areas. The most heavily altered areas are observed in the premises of active and abandoned hard coal mines (Polska, Barbara-Chorzów, Nowy Wirek), smelters (ArcelorMittal – formerly Kościuszko and Batory, Stal-Odlew – formerly Zygmunt, Pokój, Florian, Silesia and Baildon) and metallurgical (Alstom-Konstal) and chemical plants (Hajduki). Many areas are affected by post-mining deformation.

Given the location within a watershed, the hydrographic system in the map sheet area is poorly developed and highly altered by various industrial activities. The western part of the area is drained by the Potok Bielszowicki (Kochłówka)Stream and the Bytomka River, belongs to the Odra River system, whereas its eastern and central parts (Rawa River drainage basin) belong to the Upper Vistula River system. Mine waters and treated industrial and municipal sewage are discharged to surface water (Cudak, Wantuch, 2009).

River channel engineering operations result in degradation of river valleys that host industrial and post-industrial areas. Currently, the situation has been improving, although too slowly. Since 2005, there is an ongoing project called „Przyjazna Kłodnica" (The Friendly Kłodnica River), aimed at water and sediment quality improvement in the river and its tributaries (including the Bytomka River and Potok Bielszowicki Stream). The project is targeted at the elimination of contaminants from sources that are not connected to the sewage system, reduction of the contamination load in the cities, and minimizing the results of post-mining deformation (Rzeki...,).

The characteristic feature of the relief is the occurrence of vast drainless areas with water reservoirs that formed in depressions and mining subsidence troughs. One of them is the „Żabie Doły" landscape-nature protected complex located at the northern boundary of the map sheet and featured by the occurrence of several protected bird species (Michalik ed., 2003). Among the large water reservoirs that formed as a result of mining subsidence are Kalina pond and many other ponds (Marcina, Skałka, Wojskowy). Numerous water reservoirs are found in the area of Wojewódzki Park Kultury i Wypoczynku (WPKiW, culture and recreation park) in Chorzów, and near the border of Świętochłowice and Ruda Śląska (a string of reservoirs connected by a stream flowing into the Bytomka River).

Land use. Unbuilt areas cover 52% of the map sheet. These are usually scattered areas, whereas more compact ones include forests and the area of Wojewódzki Park Kultury i Wypoczynku (Pl. 2). Other unbuilt areas are represented by roadside green belts, lawns and urban parks, allotment gardens, water reservoirs and railway premises. Few areas are used as arable land (cropland and meadows).

Residential, service (services and trade) and industrial (infrastructure of coal mines, transport bases) areas are scattered throughout the map sheet. Built-up areas are represented mainly by low buildings of urban environments (20%). High urban development occupies 15%, and industrial development (mines, steelworks, metallurgical plants, landfills and mine heaps) 13% of the area.

Economy. For many years the most important sectors in the study area were coal mining and iron metallurgy, as well as zinc metallurgy in the past. The most intense development of the region dates back to the 19th century. However, from the 16th century, silver and lead ore were mined in the area of Chorzów Stary, and iron ore was extracted at several locations in Ruda Śląska, Świętochłowice and Chorzów. In the 18th century, coal mining started, followed by the establishment of iron and zinc smelters in this area (Historia Chorzów..., Historia miasta...,). With the development of the railway network, iron and zinc smelters expanded their facilities, and the development of power plants, machinery industry, metal products and other industries took place.

In the past, the most heavily industrialized area was Świętochłowice. The first coal mine (Król Saul) was established in 1825. In 1826–1835, the Quintoforo, Matylda and Franciszek mines were founded. Their mine fields occupied the area of present-day Piaśniki, Lipiny and Chropaczów. In 1823–1853, the Dawid, Constantin and Gabor zinc smelters were opened, and during the next decades the Śląsk coal mine and the Guidotto zinc smelter were established (Zmiana...,). In the Lipiny quarter, the Konstancja zinc smelter (later renamed to Silesia) was built in 1847, and in the Zgoda quarter, a number of coal mines, the Klara zinc smelter, the Zgoda (Eintracht) iron smelter, and some brickyards became active (Zmiana...,). In the 1930s, the Bethlen-Falwa (later Florian) iron smelters were established in the southern part of Świętochłowice.

Chorzów turned from a villige into a workers' settlement, and soon into a larger town around the Huta Królewska smelter (built in 1802) and the Król mine (since 1791). In 1872, the Bismarckhűtte smelter (an ancestor of the Batory smelter) was built. Until 1889, the Lydognia zinc smelter had also existed in the premises of the Huta Królewska smelter, as one of its departments (Huta Kościuszko...,).

The Bytom's Zygmunt (formerly Hubertus) smelter was established in 1845. Initially, it was a zinc metallurgy plant that, for many years, produced equipment for the steel industry in the whole country (Zamet...,). In the area of Bytom's quarter of Łagiewniki the Marien Wunsch zinc smelter was active in 1826–1870, and zinc was produced by the Godulla smelter in Ruda Śląska (Degenhardt, 1870; Szczech, 2003).

The following plants of the metallurgical and steel industries have been active within the map sheet area:
– ArcelorMittal smelter in Chorzów (formerly Huta Królewska, later Kościuszko) – currently produces rolled products, rails, and products for the mining industry,
– Batory smelter in Chorzów (in bankruptcy),
– Stal-Odlew smelter in Bytom (formerly the Zygmunt smelter),
– Pokój smelter in Ruda Śląska – manufacturer of sheet metal, profiles, and steel structures,
– ArcelorMittal smelter in Świętochłowice (formerly the Florian raw materials smelter) – manufacturer of galvanized steel sheets,
– Zakłady Metalurgiczne Silesia (metallurgical plant) in Świętochłowice (formerly the Silesia smelter).

In the south-western part of the study area, coal mining is continued in the Halemba-Wirek and Pokój coal mines.

Large plants of other industrial sectors, hazardous to the natural environment, are located in Chorzów (Michalik ed., 2003):
– Alstom-Konstal – rolling stock manufacturer,
– Zakłady Azotowe chemical plant,
–Chorzów electric power station,
–Chorzów power plant,
– Zakłady Chemiczne Hajduki chemical plant,
– Novichem – manufacturer of steam boilers and formic acid.

The major plants in Świętochłowice include (Chylat ed., 2003):
– Prinżbud – asphalt plant,
– MetalCo – manufacturer of foundry zinc alloys,
– Mostostal-Zabrze,
–Pollena-Malwa cosmetics manufacturer.

GEOLOGY AND MINERAL DEPOSITS

The map sheet area is located in the northern part of the Upper Silesian Coal Basin (USCB), within the Main Saddle anticlinal structure. Numerous boreholes and mining operations have enabled excellent exploration of the whole region. This part of the basin is featured by wide Variscan domes of Carboniferous rocks, transected by faults. In addition to

Carboniferous rocks, which form the core of the structure, there are also Triassic, Neogene and Quaternary deposits (Wyczółkowski, 1957; Buła, Kotas, ed., 1994).

Carboniferous rocks attain a thickness of a few thousand metres. Their top is found at various depths. In the central and southern part of the study area, they occur immediately under a thin Quaternary overburden or form outcrops on the surface (Pl.1). In other regions, they are found at greater depths and are overlain by Pleistocene glacial tills and glaciofluvial sands and gravels. In the north-eastern part of the map sheet the top of the Carboniferous was found at a depth of 100-200 m under Triassic limestones and dolomites of the Bytom trough and graben (Żero, 1968).

The oldest Carboniferous rocks encountered in this area are coal-bearing deposits of the Paralic Series (Namurian A). They are overlain by continental deposits represented by the Upper Silesian Sandstone Series of the Upper Namurian (Namurian B and C) and the Mudstone Series of the Lower Westphalian (Westphalian A and B). The total thickness of these series in the map sheet area is up to 2,000 m (Jureczka et al., 2005).

A characteristic feature of the Paralic Series, whose thickness is estimated here at approx. 800 m (op. cit.), is sedimentary cyclicity. The coal seams are usually overlain by claystones passing into mudstones, overlain in turn by coarse-clastic sediments: fine- and medium-grained sandstones, occasionally coarse-grained. The sandstone again grade into mudstones and claystones which are overlain by the next coal seam. The entire series contains numerous coal seams and sediments with marine, brackish and freshwater fauna. The Paralic Series of the study area occurs at a depth of over 200 m.

The Upper Silesian Sandstone Series, about 300 m in thickness (Saddle Beds and Ruda Beds), consists predominantly of fine- and medium-grained sandstones, occasionally coarse-grained, and conglomerates (Wilanowski et al., 2009). Interbeds of claystones and mudstones attain a thickness of several metres. A characteristic feature of these deposits is the frequent occurrence of coal seams, up to 5 m thick, but locally more than 10 m. The Saddle Beds host the USCB’s thickest coal seam 510, currently almost completely mined out. Deposits of this series commonly occur on the surface in the study area. Outcropping deposits are represented mainly by the Ruda Beds, locally (in the central part of Chorzów) by the Saddle Beds.

The Mudstone Series, lithologically very monotonous, is represented by the Załęże Beds corresponding to the Westphalian A, and in the uppermost part also by the Orzesze Beds of the Lower Westphalian B. The dominant lithology is mudstones and claystones with fine-grained sandstone interbeds usually attaining several metres in thickness. The whole series typically contains predominant aleuritic-pelitic sediments over coarse-clatic ones, as well as a significant number of coal cyclothems, most of them containing coal seams (*op.cit*.). Outcrops of the Orzesze Beds are found along the southern boundary of the study area, in the Witosa residential area of Katowice, and in the Kochłowice quarter of Ruda Śląska (Pl. 1). This series attains a thickness of approximately 500 m.

The Lower and Middle **Triassic** deposits unconformably overlie Upper Carboniferous rocks in the north of the map sheet. Their thickness is variable, ranging between 40 and 80 m (up to 126 m in Siemianowice Śląskie). The lithological section is represented, from base to top, by sands, sandstones, clays, claystones and mudstones of the Świerklaniec Beds, Röt dolomites, marls and limestones, limestones of the Gogolin Beds, and ore-bearing dolomites. Limestones of the Gogolin Beds, which compose most of the slopes and peaks attaining an elevation of about 310 m a.s.l., form most of extensive patchy outcrops. Subordinate lithologies include ore-bearing dolomites and Röt limestones, marls and dolomites (Strzemińska,Krieger, 2014).

Neogene deposits are represented by Miocene freshwater clays and sands, occurring as small patches in the northern part of the map sheet area.

Quaternary deposits cover about half of the map sheet area with a layer of highly variable thickness ranging from a few metres in upland areas to tens of metres in depressions and in the Kochłówka fossil valley running nearly longitudinally across the southern part of the map sheet. The Quaternary deposits are represented predominantly by glacial tills, glacial and glaciofluvial sands and gravels, and deluvial loams (locally covering the Triassic and Carboniferous rocks). They overlie directly the Carboniferous or Triassic rocks, and locally Neogene deposits.

The Holocene is represented by fluvial and swamp deposits of modern river valleys. These are fine-grained sands grading upward into swamp muds. They attain a thickness of 3 m and fill depressions, oxbow lake basins and river channels.

Large areas are covered by anthropogenic grounds that have formed as a result of long-lasting hard coal mining operations. Clusters of mine heaps and settling tanks of considerable sizes (even 2 km^2 in area) are located in Ruda Śląska-Kochłowice, Stary Chorzów, Katowice and Świętochłowice-Lipiny.

Mineral deposits. The entire map sheet area lies within the limits of the USCB and hosts **hard coal** deposits. There are 11 documented multi-level hard coal deposits: Kleofas, Wujek, Barbara-Chorzów, Śląsk, Centrum-Szombierki, Bobrek-Miechowice, Halemba, Pokój, Polska-Wirek, Rozalia and Barbara-Chorzów 1, which wholly or partly lie within the limits of the study area (Szuflicki et al., ed., 2014). The greatest economic resources of hard coal, up to 365 million tonnes, have been documented in the Halemba deposit. In the Kleofas, Bobrek-Miechowice, Śląsk, Polska-Wirek and Centrum-Szombierki deposits these are 150–170 million tonnes.

Hard coal resources have been documented to a depth of 1,000–1,050 m, or to a depth of 1,200–1,250 m in the Halemba and Śląsk deposits. The coal-bearing series is represented by coal seams of the Orzesze Beds (group 300), Ruda Beds (group 400) and Saddle Beds (group 500), and, in the northern part of the map sheet area, also of the Poręba Beds. Power coal (type 32–33) and coking coal (type 34–35) are the coal types commonly occurring in the study area. Coking coal is generally found in the lower parts of coal-bearing series located in the south of the study area (Śląsk and Halemba deposits). The thickness of individual economic coal seams varies from 1 to 10 m, but usually only the seams thicker than 2 m are mined. The quality parameters of the hard coal are highly variable. Its calorific value ranges from 16,500 to 34,000 kJ/kg, the ash content varies between 1.6 and 44%, and the sulphur content is 0.08-1.0% (sporadically up to 2%). The best parameters are typical of the coal from the Saddle Beds, which contains the smallest amount of ash (up to 10%), and up to 1% of sulphur, and its calorific value reaches 34,000 kJ/kg. These coal seams are conspicuous by considerable thicknesses and a relatively small amount of interbeds of barren rocks. Coal of the Ruda group seams is of lower quality. Coal of the Orzesze Beds is characterised by a considerable content of sulphur and ash (from several to 40%), due to numerous interbeds of barren rocks.

Most of working areas of coal mines are threatened by natural hazards by methane, dust, fire and collapse, which are of the highest risk rank and category.

Hard coal mining has a rich history in the study area, dating back to the 18th century. The Pokój Mine is among the oldest mines in the USCB. The first approved documents for coal mining activities were issued in 1752 for the Brandenburg mine (later renamed to Wawel, which is currently a part of the Pokój Mine). From 1840, coal was mined by the Kleofas mine (closed down in 2004), and in 1870, the Chorzów mine was opened.

Currently, coal seams of the Ruda and Saddle beds are extracted in the Halemba-Wirek, Pokój and Wujek mines using the high-wall mining system, sporadically with the hydraulic filling (in heavily urbanized areas). The hard coal production rates range from 0.28 million tonnes/year from the Śląsk deposit to approximately 1.65 million tonnes/year in the Halemba deposit. Power and coking coals of good parameters are extracted; they contain low amounts of sulphur (0.37–0.5%) and ash (<10%) and are highly calorific.

Coal extraction from the Barbara-Chorzów, Rozalia, Centrum-Szombierki and Bobrek-Miechowice deposits was completed in the 1990s.

Hard coal deposits are accompanied by sorbed **methane** (connected physicochemically with hard coal and dispersed coal particles). The methane content in coal increases with depth. In the study area, methane is documented down to a depth of about 1,250 m as an accompanying mineral deposit in the Barbara-Chorzów and Halemba coal deposits. It is extracted together with coal and used for heating. The total economic methane resources in these deposits are about 430 million m^3.

Of historical importance is **zinc and lead ores** in the Triassic Bytom Trough. They occurred in the Triassic ore-bearing dolomites and were among the largest and richest Zn-Pb ore deposits in the world (Szuwarzyński, 1996; Paulo, Strzelska-Smakowska, 2000). Formerly, only shallow bodies of oxidized ores (calamines) were mined. With time, also rich and then successively lower quality sulphide ores were extracted. Unprofitable ores were left in the bed or stored on the surface, and when the technology became more modern and the economic situation improved, also secondary extraction was undertaken. During the 1960s, the last mines were being successively closed down – Nowy Dwór, Waryński, Marchlewski and Orzeł Biały, and then also the new mining area in Dąbrówka Wielka near Sosnowiec (active from 1973 to 1987) due to the depletion of sulphide ores and the abandoning of Zn-Pb calamine ore processing. For this reason, the Zn-Pb ore deposits of the Bytom area are no longer registered in the national database of mineral resources (Szuflicki et al., ed., 2014). However, in dolomites and several mine heaps there are high concentrations of zinc, lead and accompanying elements, but the amounts are insufficient for industrial extraction.

The study area is rich in **clays for building ceramics**, which have been mined since the nineteenth century. Five Upper Carboniferous mineral deposits of weathering loams, clays and clay shales have been documented here: Brynów, Kochłowice II, Lech-Wirek, Polska and Chebzie-Dobra Nadzieja, as well as the Quaternary Barbara loam deposit (Szuflicki et al., ed., 2014).

Weathering loams of Upper Carboniferous clay shales are exposed on the surface or occur under a thin overburden of Quaternary sediments (usually less than a few metres thick) in the western and southern parts of the map sheet. These are bedded deposits with a simple geological structure, locally with interbeds of coals and sandstones at the bottom. The thickness of the mineral deposit reaches 20-30 m. The clays and clay shales are characterised by good quality and were used for the production of bricks and other products of building ceramics in numerous brickyards.

Quaternary loams from the Barbara deposit, used for the production of bricks, were extracted from 1900 until the 1960s. Exploitation of four other mineral deposits was completed in the 1990s. The Kochłowice II deposit still remains undeveloped.

Working pits that have formed due to the extraction of the clays, clay shales and loams are commonly used as landfills owing to very good sealing conditions, and are ultimately subjected to land reclamation. Reserves that have remained in the deposits are unrecoverable and most of them should be deleted from the national registry of mineral deposits.

HUMAN IMPACT

Natural environment in the study area has undergone transformation predominantly as a result of hard coal mining, and the metallurgical, chemical and energy industries. Industrial activities have affected the landscape and hydrographical network, as well as caused chemical alteration in soils, sediments and water.

Atmospheric air. The greatest amounts of pollutants emitted into the atmosphere are formed during the combustion of coal, natural gas and liquid fuels. Pollution from energy sources include: carbon dioxide and carbon monoxide, sulphur dioxide, nitrogen oxides, benzo(a)pyrene and particulate matter. Various industrial branches generate emissions of organic compounds (such as aromatic hydrocarbons and solvents, formaldehyde and phenol) and heavy metals.

According to the annual air quality assessment carried out by the WIOŚ (Regional Inspectorate of Environmental Protection), the permissible limits are exceeded in the study area with respect to particulate matter PM 10, carbon dioxide and benzo(a)pyrene (Raport..., 2013).

The major pollutant sources include: Chorzów thermal power station, Chorzów power plant, ArcelorMittal, Stal-Odlew, Pokój, Florian and Silesia steelworks, metallurgical plants (Alstom-Konstal) and chemical plants (Zakłady Azotowe Chorzów, Zakłady Chemiczne Hajduki, Novichem, asphalt plant, and Pollena cosmetics manufacturer).

In Chorzów, considerable amounts of gaseous contaminants are introduced into the air by the Probet Dasag, Adipol, Elkom and Mag-Met plants (Michalik ed., 2003).

The air is contaminated by periodically dusting landfills. Among the largest municipal landfill sites is that located in an area of waste heaps of the Florian Steelworks.

Emissions of odour occur mainly in the vicinity of sewage treatment plants and landfills of municipal and industrial waste. The most troublesome are the emissions of phenols from sludge accumulated in the lake of Kalina in Świętochłowice.

Surface water and groundwater. The location of the study area within a watershed zone results in the scarcity of surface water and groundwater. Throughout the entire area, surface water is heavily polluted by the discharge of saline water of coal mines, industrial and municipal sewage, and leachate from landfills. In recent years there is an on-going project of the construction of a pumping station and the elimination of outlets of untreated sewage to the rivers.

The main watercourse is the Rawa River, which flows south-eastward and is engineered along most of its course, being covered with concrete slabs. It carries wastewater mainly from the areas of Chorzów and Świętochłowice, treated in the Klimzowiec sewage treatment plant (Mucha, 2010). Natural headwaters of the Rawa River disappeared due to mining activity, although it is sometimes considered that it starts with Staw Marcina pond in Świętochłowice on the border with Ruda Śląska.

The south-western part of the map sheet area is drained by the Potok Bielszowicki (Kochłówka) Stream flowing in an engineered channel to which sewage from industrial areas of the Halemba-Wirek and Pokój mines as well as from the Barbara treatment plant are discharged.

The condition and quality of water in the Bytomka River are influenced by sewage discharges from Bytom and from the Orzegów treatment plant in Ruda Śląska. It is expected the water quality will be improved soon because the treatment plant has been modernized, and there are reclamation operations carried out in degraded areas of Bytom, where landfills of industrial waste were located in the past and the soil is polluted (Rekultywacja...,).

There are numerous water reservoir of anthropogenic origin in the study area. They have formed in drainless depressions that developed as a result of land subsidence due to mining operations (Chylat ed., 2003; Plewniak 2007; Gorol 2011). Among the major reservoirs are the following ponds: Żabie Doły, Gliniok, Staw Marcina, Maroko and Magiera ponds. Some of these reservoirs contain good quality waters and are used for recreational purposes.

The water of Kalina Lake, in which toxic sediments were accumulated, are strongly polluted due to the activity of the already inactive Zakłady Chemiczne Hajduki chemical plant that produced paints and varnishes over about 50 years (Wantuch, Cudak, 2009). Industrial waste of the plant was stored on a heap from which the leachate penetrated into the lake. Currently, the heap is covered with a layer of soil, and vegetated.

The pollutants affecting the quality of surface water penetrate also into groundwater of the Quaternary, Triassic and Carboniferous formations. The map sheet area is devoid of usable aquifer. The Quaternary multi-aquifer formation is degraded due to draining operations in coal mines, and mining and smelting of zinc and lead ores in the past, and as a result of infiltration of precipitation that captures pollution from the atmosphere and from the ground surface. The Triassic multi-aquifer formation is unconfined or partially covered with Quaternary deposits, and is not usable. The water table of the Carboniferous multi-aquifer formation has been degraded and lowered as a result of mining activities (Cudak et al., 2009; Wantuch, Cudak, 2009).

Soils. Almost the entire map sheet is occupied by mining areas of active or abandoned coal mines and post-mining deformation, in which the soils show strong anthropogenic alterations. Brownfields include: coal waste heaps, zinc and lead mining heaps, energy industry waste heaps, iron metallurgy waste heaps, piles and settling tanks of non-ferrous industry, limestone quarry heaps, chemical waste and sewage sludge heaps, and landfills of municipal solid waste (Jechna ed., 2012).

In these areas, natural components of soils are mixed with foreign materials, often repeatedly digged and desiccated. Due to the location of numerous industrial facilities and intense urbanization, agricultural soils occur over very small areas, mainly of allotment gardens.

Soil pollution is also associated with the historical exploitation and smelting of zinc and lead ore, steel industry, and the impact of mining waste (gangue heaps, sludge settlers, coal slurry, mine water), waste of steel industry (slag and oily mill scales), energy industry and chemical industry, as well as particulate matter emissions from industrial plants and transportation. Sometimes, the dissemination of contaminants penetrating into the soil is facilitated by the use of mining waste in the reclamation of brownfield sites, road construction and water engineering. The results of soil monitoring have shown that the permissible limits of metals concentrations are dramatically exceeded (Sordoń-Kulibaba, 2010).

Landfills. There are many landfills of slag and mining waste near historical and present-day metal smelters in Ruda Śląska, Świętochłowice and Chorzów.

In the western part of Świętochłowice, in a working pit of a slag heap of the Florian Steelworks, there is an active municipal landfill. To the west there are industrial areas of the Pokój Steelworks, to the east – a railway siding, and, further on, allotment gardens extend. To the north of the landfill there are tailings heaps and industrial areas of the historical zinc smelters of Constantin and Gabor. An inactive municipal landfill site is situated in Żelazna Street in Świętochłowice. It is located in a loam pit where slag was stored. After removal of the slag the disposal of municipal waste began. The waste was deposited without ensuring adequate safety measures, so it can pose a threat to groundwater (*op.cit.*). In Świętochłowice there are also small partially levelled heaps of historical waste of the Klara and Franciszek smelters (Brodziński et al., 2004). Another mine heap in the northern part of the city is the so-called Ajska heap of mining waste from the Śląsk-Matylda coal mine and industrial waste of the Silesia plant. The heap (32.8 ha in size) has been partly reclaimed and developed to create as a recreational area (a motocross track).

Heaps of iron-smelting waste are located near the steelworks and smelters. These are predominantly slag and, in a smaller amount, molding sand, refractory debris, sludge and post-treatment sediments. Slag is used as road aggregate (*op.cit.*).

The largest mining waste heaps are located near closed and active coal mines.

MATERIALS AND METHODS

Research conducted in the years 2013–2016 included a study of published and archival materials, location of soil sampling sites on 1:10,000 topographic maps, sample collection, and measurements of geographic coordinates at sampling sites, chemical analysis of samples, development of field and laboratory databases, development of vector topographical base map, statistical calculations, compilation of geological map and construction of geochemical maps, and interpretation of study results. The sequence of workflow steps is illustrated in the attached diagram (Fig. 1).

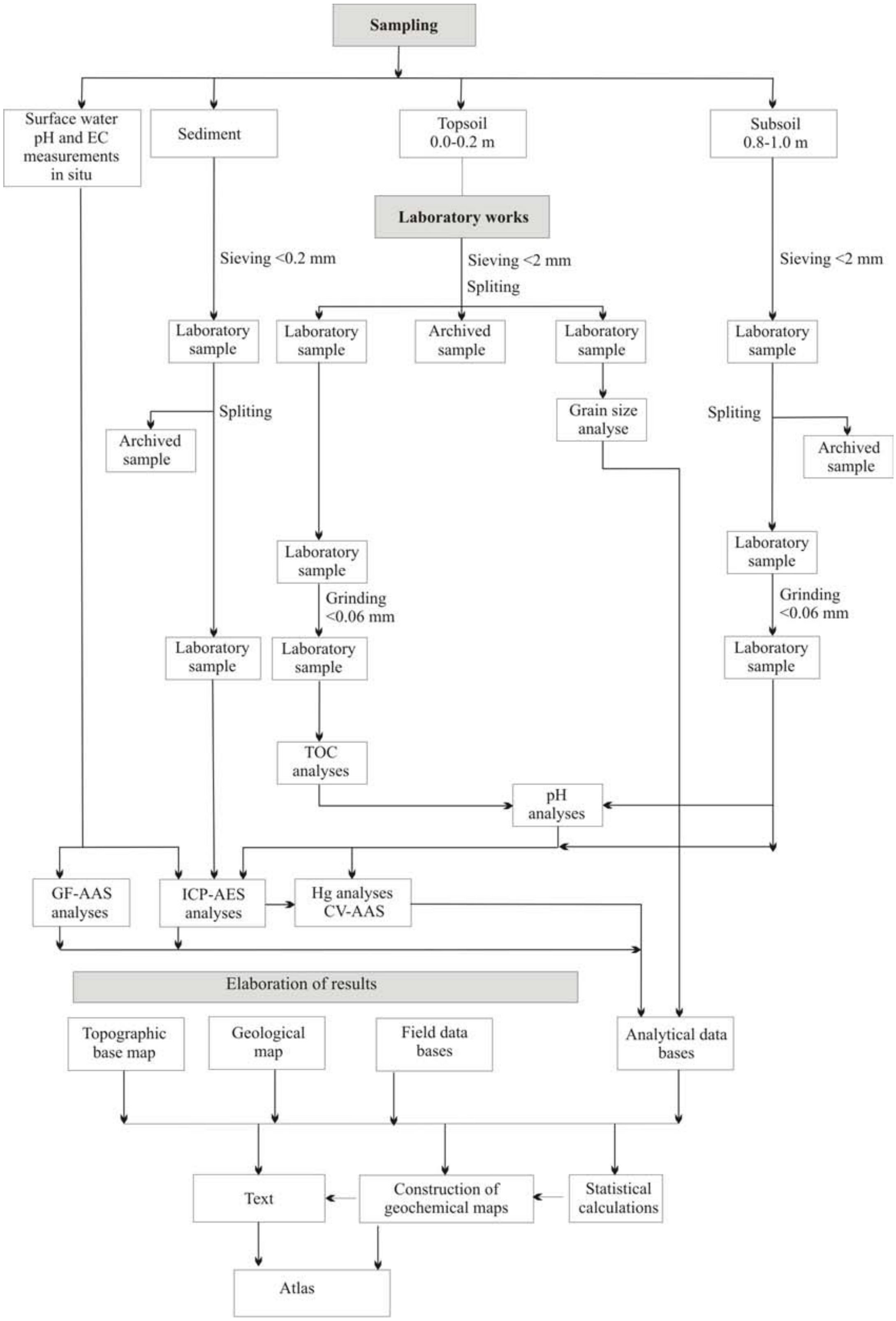

Fig. 1. The study procedure

FIELD WORKS

Soil samples were collected on a basis of a regular grid of 250x250 m (16 samples per km^2). The total number of soil sampling sites was 1,441. At every site, the samples were collected from two depths of 0.0–0.3 and 0.8–1.0 m (or from a smaller depth if the parent rock was found at a shallower depth). Soil samples (ca. 500 g) were collected using a 60-mm hand probe, put in linen bags labelled with numbers, and pre-dried on wooden pallets at a field storage site.

Samples of sediments and surface water were collected from rivers, streams, melioration ditches, canals and ponds. The distance between sampling sites along watercourses was about 250 m. Sediment samples weighing about 500 g (as fine-grained as possible) were taken from the water reservoir shores using a scoop. They were subsequently placed in 500-ml plastic containers, each labelled with a number.

Surface water samples were collected from the same sites as sediment samples. Electrolytic conductivity (EC) and acidity (pH) of water were measured on site. Conductivity was measured using conductivity meter with automated temperature compensation, assuming the reference temperature of 25°C. Water samples were filtered in situ using 0.45-μm Millipore filters and acidized with nitric acid in 30-ml bottles. The bottles were also labelled with numbers.

All the sampling sites were indicated in topographic maps at a scale of 1:10,000 and numbered.

Locations of the sampling sites were defined with GPS, using a device equipped with an external antenna and a computer which can record not only coordinates but also additional information (pH and EC of water samples, data on land development and land use as well as on lithologies). The geographic coordinates were taken with an accuracy of ±2 – 10 m.

The coordinates of soil sampling sites were put into the memory of the GPS equipment, before going out in the field, and the sites were subsequently found using the satellite positioning system. For safety reasons, all the field data were also recorded on special sampling cards (Fig. 2).

POLISH GEOLOGICAL INSTITUTE
Detailed geochemical map of Upper Silesia 1:25 000
Sheet ....

Date..................
Sampler
....

Sample number

1					
2					

Soil

topsoil	0.0-0.3 m
subsoil	

Coordinates

X	
Y	

District..................................Community..Place.....................................

Land development

1		non-built areas
2		village development
3		urban areas with low development
4		urban areas with high development
5		industrial areas

Land use

1		cultivated field
2		forest
3		meadow
4		barren land
5		lawn
6		park
7		allotment

	Sample 1	2	**Type of soil**
1			sand
2			sand-clay
3			clay-sand
4			clay
5			till
6			silt
7			peat
8			man-made

Notes...
....

A

POLISH GEOLOGICAL INSTITUTE
Detailed geochemical map of Upper Silesia 1:25 000
Sheet ....

Date..................
Sampler
.

Sample number

Sediment	3				
Water	4				

Coordinates

X	
Y	

District.............................Community..............................Place...............................Water body ....

Land development

1		non-built areas
2		village development
3		urban areas with low development
4		urban areas with high development
5		industrial areas

Land use

1		cultivate land
2		forest
3		meadow
4		barren land
5		lawn
6		park
7		allotment

Water body

1		river
2		stream
3		canal
4		ditch
5		lake
6		pond
7		fish pond
8		settling pond

Sediment

1		sand
2		organic mud
3		silt
4		clay

Notes...
....

B

Fig. 2. Sampling cards of soils (A) as well as sediments as surface water (B)

LABORATORY WORKS

Sample preparation. After transferring to the laboratory, the soil samples were air-dried and sieved through a 2-mm nylon sieve. After sieving and quartering, each topsoil sample (from a depth of 0.0–0.3 m) was split into three portions: one of them was submitted for chemical analysis, the second one was analysed for grain-size, and the third one was archived. Each subsoil sample (from a depth of 0.8–1.0 m) was sieved and quartered and then split into two portions: one of them was submitted for chemical analysis, and the other one was archived (Fig. 1). The soil samples for chemical analyses were pulverized in agate planetary ball mills to a grain size <0.06 mm.

Sediment samples were air-dried and then sieved through a 2-mm nylon sieve to a grain size <0.2 mm. After quartering, the <0.2 mm fraction was divided into two portions: one of them was used for chemical analysis, and the other one was archived (Fig. 1).

All the archived samples are stored at the Polish Geological Institute – National Research Institute in Warsaw.

Chemical analyses. Soil and aqueous sediment samples were *aqua regia*-digested (1 g of sample to final volume of 50 ml) for 1 hour at the temperature of 95^{o}C in a thermostat aluminium block.

The contents of Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, S, Sr, Ti, V and Zn in soils and sediments were determined by the inductively coupled plasma-atomic emission spectrometry (ICP-AES) method. Determination of Hg in soil and sediment samples was performed using the cold vapour-atomic absorption (CV-AAS) method with the FIAS-100 with flow injection system. Soil pH was measured in water extractions using a pH-meter. Organic carbon content was measured using the coulometric method (with the detection limit 0.16%), high-temperature combustion and detection with thermal conductivity TCD, and high-temperature combustion with infrared spectrometric detection (with the detection limit 0.01–0.02%).

The contents of B, Ba, Ca, Cr, Fe, K, Mg, Mn, Na, P, SiO_2, SO_4, Sr, Ti and Zn in surface water were determined by the ICP-AES method, and the contents of Ag, Al, As, Be, Cd, Co, Cu, Li, Mo, Ni, Pb, Sb, Se, Tl, U and V were analysed using the ICP-MS method.

The applied analytical methods and the detection limits of chemical elements are shown in Table 1.

The quality control of the determinations was performed through analysis of duplicate samples (5% of all samples), analysis of reference materials with certified content of elements studied (2% of all samples), and analysis of laboratory control samples confirming correct instrument calibration (5% of all samples).

Purity of reagents and vessels was controlled with “reagent blank samples” and „procedural blank samples”.

The expanded uncertainty of results (with the assumed probability level of 95% and coverage factor k = 2) for water, soil and sediment samples does not exceed 25%.

Grain-size analysis of topsoil samples (0.0–0.3 m) was carried out at the PGI-NRI Soil and Rock Laboratory Testing Centre in Warsaw, combining the sieve analysis with the laser particle size measurement method. The grain-size analysis was conducted using unconventional methods (not in accordance with the relevant standards in soil science). Their results cannot therefore be used to classify the soils according to the soil science criteria. However, they are very helpful when interpreting the results of geochemical research.

The samples were sieved through a set of 2-mm, 1-mm and 0.5-mm sieves. Samples of some loamy soils were crumbled in a porcelain mortar before sieving. The obtained fractions of 2–1 mm, 1.0–0.5 mm and <0.5 mm were weighted. Measurements of grains from the <0.5-mm fraction were performed with use of a laser particle size analyser.

The results of grain-size analyses (recalculated to percentage ranges) are presented in the maps with respect to the following grain-size classes: sand fraction 1.0–0.1 mm, silt fraction 0.1–0.02 mm, and clay fraction <0.02 mm (Pls. 4–6).

DATABASES AND CONSTRUCTION OF GEOCHEMICAL MAPS

Base topographic map. The 1:25,000 geochemical maps were constructed based on 1:50,000-scale topographic base map in the *1992* coordinate systems, Zabrze M-34-62-B map sheet (vector map VMap L2). The topographic map contains the following vector-information layers: relief, hydrography (including categorisation into rivers, streams, ditches and stagnant water reservoirs), road communication network (with road classes indicated), railway network, land development (including subdivision into rural, urban and industrial development), forests, industrial areas (industrial facilities, mine excavations, mine heaps, and tailing ponds).

Geological map. To illustrate the geological structure of the study area, the Zabrze M-34-62-B map sheet of the 1:50,000-scale Detailed Geological Map of Poland was used (Wyczółkowski, 1957). Individual elements of the geological map were digitized to create their vector images that were subsequently combined with the topographic base, producing a geological map at the scale of 1:25,000 (Pl. 1).

Databases. Separate databases were prepared for: topsoil from a depth of 0.0–0.3 m, subsoil from a depth of 0.8–1.0 m, sediments and surface water.

Soil databases contain the following information: sample number, results of measurements of geographic coordinates at sampling sites, site description (land development, land use, soil type, sampling site location – district, commune and locality), date of collection, name of sample collector, and analytical data.

Sediment and surface water databases contain the following information: sample number, results of measurements of geographic coordinates at sampling sites, site description (land development, land use, water body type, sediment type, sampling site location – district, commune and locality), date of collection, name of sample collector, and analytical data.

Statistical calculations. The results gathered in databases were used to create subsets for statistical calculations according to different environmental criteria, e.g. concentrations of elements in soils of industrial areas, forest soils and urban soils, in sediments, and in the water of individual water bodies, as well as for geochemical map construction. Statistical calculations were made for both whole datasets and subsets created for soils, sediments and surface water. In the case of some elements with the content lower than the detection limit value for the given analytical method, half of the detection limit value was taken. The arithmetic and geometric means, median, and minimum and maximum values were calculated. These data specified for individual elements and indices are shown in Tables 2–5 and presented in the geochemical maps.

Median values were the most commonly used parameter to interpret the results, as a measure of the average contents of each element. The median is a statistical parameter that better characterises the average contents than the arithmetic mean, because it is less affected by extreme values. Other statistical parameters (variance, standard deviation) are not suitable for the characteristics of the population with unspecified distribution.

Maps construction. The following maps were produced for the Chorzów Sheet (Pls. 2–63): land development; land use; contents of organic carbon, and sand, silt and clay fractions in topsoil (0.0–0.3 m depth); pH of topsoil and subsoil (0.0–0.3 and 0.8–1.0 m depth); contents of Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Ni, P, Pb, S, Sr, Ti, V and Zn in topsoil, subsoil and in sediments; pH, electrolytic conductivity and contents of Ag, Al, As, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, SO_4, Sb, Se, SiO_2, Sr, Ti, Tl, U, V and Zn in surface water; classification of topsoil (0.0–0.3 m), indicating its proper use (including subdivision into soil use groups based on the Regulation of the Ministry of the Environment (Rozporządzenie..., 2002).

Land development, land use and classification of topsoil (0.0–0.3 m) in relation to soil use are presented as dot maps (Pls. 2, 3 and 63).

To show the distribution of grain-size classes (Pls. 4–6) and the contents of elements in soils, contour maps were constructed because of their clarity and legibility. The geochemical contour maps were produced using the Surfer software and the *Inverse Distance to a Power* method. The classes of contents of elements were created using geometric progression.

Soil pH (Pls. 7 and 8) is presented according to the soil science classification (acidic, neutral and alkaline soils).

The geochemical maps of soils were constructed using the analytical dataset created for the Chorzów Sheet and the adjoining 1:25,000-scale sheets to avoid any discrepancies at the sheet boundaries. The Chorzów Sheet was then compiled from mono-element maps and combined with the topographic base map.

The geochemical maps of sediments and surface water for the Chorzów Sheet were compiled separately. They were constructed as dot maps with the circle diameters corresponding to individual classes, most often according to geometric progression.

While constructing the map of soil classification (Pl. 63), indicating appropriate soil use, the results of geochemical analyses were referred to the permissible concentrations of metals, defined in the Regulation of the Ministry of the Environment. According to the recommendation: “soil or land is considered polluted if the concentration of at least one substance exceeds the permissible limit value” (Rozporządzenie…, 2002).

Based on the concentrations of individual metals analysed (specified in Rozporządzenie..., 2002), each soil sample was categorized into class A, B or C. In the case of equal permissible limit values for classes A and B (based on guideline values for arsenic, barium and cobalt in Rozporządzenie..., 2002), the soil was categorized into class A, which is more beneficial for the soil user and enables multifunctional land use.

For publication purposes, the geochemical maps were constructed by combining the maps into pairs: i.e. the topsoil map is presented on the same Plate together with the aqueous sediment map, and the subsoil map is shown together with the surface water map on another Plate. This method of presentation provides the possibility of direct comparison of geochemical images of various environments.

To facilitate easy use of the atlas, the maps (with a bar scale shown) have been printed out in a slightly smaller format (A3). This operation does not result in missing any important details of the maps.

RESULTS

SOILS

In the Chorzów Sheet the soil parent rocks are represented by various Carboniferous, Triassic and Quaternary deposits (Pl. 1) that gave rise to different types of soils. Limestones and dolomites were the bedrock for rendzina soils, whereas Quaternary tills were the parent deposits of brown and lessive soils. Podzols and pseudopodzols have developed from the Carboniferous sandstones and Quaternary glaciofluvial sandy sediments. Large areas are covered with anthropogenic soils of considerable thickness (Michalik ed., 2003; Sordoń-Kulibaba, 2010). They occur in reclaimed post-industrial areas or naturally vegetated post-mining areas. These soils frequently develop on a parent rock of quite different properties than that on which the original soil cover developed. An example is soils that developed in areas of bootleg mine shafts. These soils have formed on material that is extracted from deeper zones. Anthropogenic soils cover man-made escarpments, reclaimed mine heaps and some allotment gardens, or occur in river channels of altered watercourses (Duriasz, Cupiał, 2009).

Economic activity has contributed to major changes in the soil profiles and their physicochemical properties. Degradation processes occur primarily in the areas of industrial facilities, waste storage sites, built-up areas, near communication routes and in areas of mineral extraction.

Grain size. The percentage of particles of specified sizes in the soil is called mechanical composition, grain-size composition, granulometric composition or grain-size distribution (Mocek et al., 2000; Ryżak et al., 2004, 2009). Under natural conditions, the soil grain-size composition changes insignificantly (excluding saline soils, in which peptization of soil colloids can occur), being one of the main features affecting soil's physical, chemical and biological properties.

For the purpose of this report, the classification of particles into grain-size groups follows the standard BN-78/9180-11, which has been valid since 2008, because this is a continuation of a serial publication performed over a long period in accordance with the instruction to the 1:25,000-scale geochemical map. The results of grain-size analysis are presented for the following grain-size groups: 1.0–0.1 mm sand fraction, 0.1–0.02 mm silt fraction, <0.02 mm clay fraction (Pls. 4–6). The change in the grain-size ranges in accordance with the guidelines of the Polish Society of Soil Science (PTG) (Klasyfikacja..., 2008) would make it impossible to compare the grain-size composition with data from previously compiled map sheets.

Grain-size composition of soil largely determines its resistance to degradation and has a significant effect on the content of chemical elements. Soils that contain a high proportion of clay and silt fractions are usually characterised by increased contents of elements and their reduced mobility in hypergenic conditions. Compared to sandy soils they are more resistant to the removal of plant nutrients and can retain a greater amount of toxic components (including heavy metals) without harming the environment.

In the topsoil of the map sheet area the original grain-size composition has been significantly obscured by results of earthmoving and construction works (especially in industrial and urban areas). Considerable proportion of anthropogenic soils is manifested in the maps as a mosaic pattern of distribution of the content of individual grain-size fractions (Pls. 4-6.).

Predominance of glacial tills as the parent rocks results in the greatest percentage of soils abounding in the silt fraction (0.1–0.02 mm). Over much of the map sheet area the topsoil contains >40% of this fraction. These soils contain also 10–15% of clay fraction (<0.02 mm) that accounts (especially in the east of the map sheet) for more than 20%.

Soils that developed on Carboniferous sandstones and Pleistocene glacial, glaciofluvial and fluvial sediments contain >40% of sand fraction (1.0–0.1 mm).

Acidity. Alkaline soils predominate in both the topsoil (0.0–0.3 m) and subsoil (0.8–1.0 m) layers. In this group the proportion of soils with pH >8 in the topsoil is 36%; in the subsoil it is even 46%. The largest massive area of strongly alkaline soils (pH >8) covers the central part of the map sheet (the most industrialized area) and the areas located near metal smelters in the western part.

One of the reasons for the alkalization of the topsoil is the many years' emission of particulate matter from the combustion of coal, in which the CaO content can be up to 32.6% (Ratajczak et al., 1999). Other alkalizing factors include using of agents for snow removal from streets, periodic dusting from mine, slag and furnace waste dumps, and dispersion of dust from small quarries of Triassic limestones and dolomites extracted for local needs. A higher proportion of alkaline soils at a depth of 0.8–1.0 m can be associated with a greater amount of alkalizing materials (construction and industrial waste) and the proximity of local carbonate rocks in the deeper parts of the soil profiles.

Acidic soils (pH <6.3) occupy very small areas as regards both the topsoil and subsoil, and occur as minor patches in the forests close to the southern boundary of the map sheet and in its eastern part (in and around the WPKiW Silesia Park in Chorzów).

Geochemistry. Anthropogenic transformations have led to so significant changes in the chemical composition of the soils in relation to the parent rocks that the basic geochemical features of the original rocks in the topsoil are very poorly visible. The spatial distribution of the elements analysed indicates the presence of pollution originating from various industrial activities.

In the topsoil the distribution of elements (aluminium, barium, calcium, cobalt, magnesium, manganese, nickel, phosphorus, strontium, titanium and vanadium), which are derived mainly from the parent rocks, has been disturbed by anthropogenic factors. Comparison of the median values shows that their contents far exceed the values of the geochemical background in the Silesian-Cracow region (Tab. 2). The approximately two-fold enrichment compared to the regional background is observed in the case of manganese and cobalt, three times greater values are recorded for calcium, magnesium, vanadium and nickel, and four times greater values - for barium, strontium and titanium. The highest amounts of accumulated elements originate from emissions into the environment from metal smelters. The lead and copper contents are five times greater than the geochemical background value in the region, and the zinc content is seven times greater.

In the south of the map sheet, where outcrops of Carboniferous sandstones and mudstones and Pleistocene sandy sediments are predominant, both the topsoil and subsoil commonly contain 0.40–0.80% of aluminium. In the north, where glacial tills and outcrops of Triassic carbonates are found, the aluminium content varies between 0.80–1.60%. The greater amount of aluminium is associated with the occurrence of aluminium-rich components in the fine-grained parent rocks of soils (feldspars, micas and clay minerals).

Both the topsoil and subsoil are rich in barium (120–480 mg/kg). The natural sources of this element are outcrops of Carboniferous and Triassic clay rocks. Markedly greater areas of barium-rich topsoil allow the conclusion that the barium accumulation is related to the scattering of particulate matter by the industrial sector (smelters and thermal power plants) and to the drainage of mine heaps. The prevalence of anthropogenic sources of barium is demonstrated by the median value in topsoil which is twice as much as in the subsoil.

The organic carbon content in the topsoil varies in the range of 0.2–55.2%. The lowest proportion of organic carbon (<3%) is found in soils developed on Quaternary sandy deposits in the Potok Bielszowicki Stream valley and in the WPKiW Silesia Park in Chorzów. In the soils developed on Quaternary glacial tills and Triassic carbonates the content of this constituent commonly varies between 3 and 6%. The median value of organic carbon content in the forest soils is 4.9%, and in the cropland soils – 2.8% (Tab. 2). The values of >6% are typical of soils within a belt of urban and industrial areas in the west of the map sheet. In industrial areas of hard coal mines the organic carbon content exceeds 12%, locally even 24%.

The characteristic association related to the presence of carbonate rocks in the basement is represented by calcium, magnesium, manganese and strontium. Soils naturally enriched in these elements (>2% calcium, >0.50% magnesium, >800 mg/kg manganese and >80 mg/kg strontium) occur in the northern quarters of Chorzów and in Łagiewniki of Bytom. High content of calcium and manganese is benefit to soils, increasing its alkalinity and favouring bonding of heavy metals. Near the Pokój and Florian steelworks the contents of these elements are similar, but they are derived from the dispersion of particulate matter by technological processes rather and from the storage of materials and industrial wastes. The maximum contents of manganese and strontium are found in soils close to iron steelworks.

The content of phosphorus in the topsoil is almost twice as high as in the subsoil (the median values are 0.045% and 0.023%, respectively). In the topsoil, a greater amount of phosphorus is found in the soils of allotment gardens and urban lawns, which can be explained by the use of phosphate fertilizers.

Most of the soils from both depth intervals contain below 0.080% of sulphur. The amount of sulphur at the level of >0.160% was found near industrial plants and their landfills (Kopyto sludge dump, Silesia Steelworks, region between the Florian and Pokój steelworks, Nowy Wirek mine). The probable source is pyrite that accompanies coal-bearing rocks, and fuel used in the steelworks.

In areas of mining activity, around historical and modern metallurgical plants, as well as near mine heaps and waste dumps there are numerous anthropogenic anomalies of silver, arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc.

Anomalies of silver (>1 mg/kg), arsenic (>40 mg/kg) and cadmium (>8 mg/kg), which show similar extents in both the topsoil and subsoil, have been found in the north-western part of the map sheet, in the Rawa River valley, and near the Witosa residential area of Katowice. Extreme values of these elements occur only on a local scale. The areas most polluted by these elements include the northern quarters of Świętochłowice, eastern quarters of Ruda Śląska and the border area between Bytom and Chorzów. The soil pollution with metals is associated mainly with the historical activity of zinc smelters and their unsecured waste dumps. In different periods, zinc was produced in these localities in the following smelters: Marien Wunsch, Guidotto, Godulla, Konstancja, Constantin, Gabor, Klara and Dawid. Moreover, zinc-processing plants operated in the premises of the former Zygmunt smelter (in the beginning of its activity), and as one of the departments of the Huta Królewska (Lydognia) smelter in Chorzów (Degenhardt, 1870; Szczech, 2003; Huta Kościuszko...; Zmiana...,). Soils heavily polluted with arsenic, cadmium, lead and zinc are found near the Kopyto sludge dump, in the premises of the former Guidotto zinc smelter, near the Silesia and Florian steelworks in Świętochłowice, and near the Żabie Doły nature reserve on the border of Bytom and Chorzów. In the north-eastern part of the study area, a certain portion of the metals in the soils may originate from weathering of outcropping ore-bearing dolomites that were extracted in the past.

The largest area of silver anomaly (>2 mg/kg) in the topsoil covers the Silesia Steelworks–Godula–Chropaczów region. The maximum concentration of this metal (97 mg/kg) was recorded near Lipińska Street in the Godula quarter of Ruda Śląska, where the Godulla zinc smelter was probably located (Degenhardt, 1870). Near waste dumps of the Silesia Steelworks, the concentration of silver is 55 mg/kg silver, and near the Kopyto sludge dump 34 mg/kg. In the other areas of the map sheet (Żabie Doły, surroundings of the ArcelorMittal Steelworks, Witosa residential area in Katowice) distinct silver anomalies at a depth of 0.8–1.0 m originate probably from the activities of smelters and from dumping of sludge waste.

Anomalies of arsenic (>80 mg/kg) and cadmium (>16 mg/kg) in soils are observed in the areas of anomalous silver contents, but are also found at other locations (in the Bytomka valley, near the Florian Steelworks and in the premises of the Michałkowice metallurgical plant). The topsoil strongly polluted by arsenic is also found near the Kopyto sludge dump (5,288 mg/kg) and in the Silesia Steelworks dumps (3,266 mg/kg). Near the Kopyto sludge dump the subsoil layer contains 5,300 mg/kg of arsenic.

The worst soil pollution is due to the accumulation of lead accompanied by zinc. Areas of strong anomalies of these elements coincide with the silver, arsenic and cadmium anomalies, but also cover the regions of historical and modern iron smelters (ArcelorMittal, Florian, Pokój, Batory, Zygmunt and Baildon). Commonly observed pollution is by lead >100 mg/kg (81.61% of samples) and zinc >500 mg/kg (66.28% of samples) in the topsoil, but also in much of the subsoil (Tab. 6).

A massive area of lead (>250 mg/kg) and zinc (>1,000 mg/kg) anomaly in both the topsoil and subsoil is found around the Zygmunt smelter in Bytom, in the north-western quarters of Świętochłowice (Chropaczów, Lipiny, surroundings of the Florian Steelworks) and in the eastern quarters of Ruda Śląska (Godula, Chebzie, industrial areas of the Pokój Steelworks and Pokój mine). Within the anomaly, the most polluted soils near the Kopyto sludge dump contain up to 16,110 mg/kg of lead and up to 36,930 mg/kg of zinc. The area around the sludge dumps of the Silesia Steelworks is covered with soils containing up to 15,810 mg/kg of lead and up to 13,930 mg/kg of zinc, whereas near the waste dump in the Nowowiejska residential area in Świętochłowice the lead concentration is 12,450 mg/kg and the zinc concentration is 33,760 mg/kg.

Near the northern boundary of the map sheet, the topsoil is considerably polluted by lead (up to 54,940 mg/kg) and zinc (up to 30,010 mg/kg) close to the water reservoirs of Żabie Doły, which were the area of storage of waste after processing of zinc and lead ores (Cempiel et al., 2014).

In Chorzów, the maximum concentrations of lead and zinc are found in soils of industrial areas of the Zakładów Azotowe chemical factory and the ArcelorMittal and Batory steelworks.

In Katowice, the metal anomalies show small areal extents. They are found in the Rawa valley, which can be associated with contamination of alluvial soils during high water levels, and around industrial facilities in the Witosa residential area.

Pollution of soils by chromium, cooper, iron and nickel, as well as enrichment in manganese, titanium and vanadium (which originate from ores and special additives to steel) is associated with the activity of iron smelters. Dispersion of calcium and strontium is dependent on their content in fluxes. Anomalies of these metals have been discovered in soils around the historical and currently active smelters: Zygmunt, Silesia, Pokój, Florian, Batory, ArcelorMittal and Baildon. Soils that contain >40 mg/kg chromium, >2% iron, >40 mg/kg nickel, >80 mg/kg copper and >40 mg/kg vanadium occupy much greater areas in the topsoil compared with the subsoil, which indicates their anthropogenic origin.

The most polluted with chromium (1,317 mg/kg), copper (13,230 mg/kg), mercury (0.50 mg/kg) and nickel (306 mg/kg) is the topsoil within the premises and in the vicinity of the Florian Steelworks. Near the Silesia Steelworks (in the Lipiny quarter of Świętochłowice) the soils contain >160 mg/kg chromium, >40 mg/kg nickel and >4% iron. In turn, near the ArcelorMittal Steelworks the following values were measured: >80 mg/kg copper, >4% iron and >40 mg/kg vanadium. The maximum nickel concentrations in the topsoil (433 mg/kg) and 587 mg/kg in the subsoil were found in the area of the former Baildon Steelworks. These soils are also polluted by chromium (180–420 mg/kg), copper (140–210 mg/kg) and iron (4–9%).

Mercury-polluted soils (>0.20 mg/kg) are found in both depth intervals, but the topsoil anomalies show a greater areal extent. The topsoil's strongest mercury anomaly (at a maximum of 23.44 mg/kg) is found in the Pokój Steelworks area. Near Lake Kalina and in the allotment gardens close to a mine heap of the Nowy Wirek coal mine, the mercury concentration exceeds 0.80 mg/kg. At a depth of 0.8–1.0 m, the maximum mercury concentration (23.04 mg/kg) was found near Imieli Street in Świętochłowice.

Because of the ease with which cadmium, lead and zinc are accumulated, and harmful effects of their excess to plants and micro-organisms living in the soil, the percentage of areas polluted to different degrees by these metals has been estimated within the map sheet (Tab. 6). The most clearly marked pollution is by lead and zinc. In the topsoil, 66.28% of soils contain >500 mg/kg of zinc, 61.83% of soils >4 mg/kg of cadmium, and 81.61% of soils >100 mg/kg of lead. At a depth of 0.8–1.0, the percentage of soils polluted with these metals is lower.

Soils from a depth of 0.0–0.3 m were evaluated for the degree of pollution by metals, classifying them into the soil use groups A, B and C, based on permissible limit values (Rozporządzenie…, 2002). While using the summary classification, we used the principle that the soil is categorised into a given group if the concentration of at least one element exceeds the permissible limit value. With respect to the content of metals (purity that meets the requirements of protected areas), 1.53% of the soils have been categorised into group A. Group B (soils useful for agricultural and forest cultivation) is represented by 10.06% of the samples analysed, and group C (soils useful for industrial and transportation purposes only) is represented by as much as 88.41% of the samples (Tab. 7). The criteria required for soil's multifunctional use are met by the soils assigned to groups A and B. The most polluted soils, classified as group C, occur in the western and central parts of the map sheet, in industrial areas (Pl. 63). The discussed soil classification indicates how the given area should be used in accordance with the guidelines of the Ministry of the Environment (Regulation ..., 2002). In many cases, the current land use is inappropriate and requires monitoring and remediation. The concentrations of metals in soils of some woodland and garden areas are so high that they should be used only as industrial areas.

SEDIMENTS

In the map sheet area, the analysis of sediments was performed in the Bytomka, Potok Bielszowicki (Kochłówka) and Rawa watercourses, their tributaries, and in numerous water bodies formed as a result of underground mining operations. Chemical properties of water and sediments of these reservoirs show high peculiarity, and the number of the water bodies is so great that the whole region can be referred to as „*anthropogenic lakeland*" (Rzętała, 2008; Schultze, Boehrer, 2008; Jachimko, Kasprzak, 2011; Rzętała, Jaguś, 2012). Sediments of inland water bodies are deposited from mineral and organic suspension that originates from erosion and precipitation of particles contained in the water. Their chemical composition is dependent on the lithology and land use within the drainage basin area (Hoth et al., 2005; Blodau, 2006; Hrdinka, 2007; Zgłobicki, 2008; Hinwood et al., 2012; Cánovas et al., 2015).

In industrial, urban and agricultural areas, sediments are polluted by potentially harmful trace elements and organic compounds carried by the leachate of waste dumps, as well as those contained in industrial and municipal sewage discharged to surface water, and in runoff water (Ciszewski, 1997, 2002, 2005; Matschullat et al., 1997; Miller 1997; Swennen, Van der Sluys, 2002; Bojakowska et al., 2006; Harnischmacher, 2007; Kozieł, Zgłobicki 2010; Lagauzère et al., 2011; Govil et al., 2012; Cempiel et al., 2014).

Concentration of metals (zinc, copper, chromium, cadmium, lead and mercury) and organic compounds in sediments affects adversely the quality of surface water. Contaminants from the sediments can accumulate in the trophic chain up to the concentrations that are toxic to aquatic organisms, and pose a risk to humans and animals consuming fish or shellfish that feed at polluted sites. Harmful constituents of the sediments may be re-mobilized into the water following various biological, chemical and physical processes (Friese, 2002; Harnischmacher, 2007). Contaminated sediments that are displaced into floodplains also cause an increase in the concentration of heavy metals in soils of river valleys (Ibragimov et al., 2010).

Bytomka River and its catchment. The upper reach of the Bytomka River, called the Bytomska Woda, begins near the Bytom-Karb railway station and is recharged mainly by mine water (Cempiel et al., 2014). The river flows across urban areas, locally in a deep valley with water reservoirs and wetland areas (Działoszyńska-Wawrzkiewicz, 2007). The area of the upper part of the Bytomka drainage basin (north of the map sheet area) is occupied by the industrial and urbanized district of Bytom. In this area there are mine shafts and settling tanks of the inactive coal mines of Szombierki and Rozbark and of the active Bobrek coal mine, and there is also the Bytom railway station. Some contaminants found in the Bytomka sediments may originate from these sources. Previous studies demonstrated considerable pollution of Bytomka sediments by chromium, cadmium, zinc, lead and copper (Nocoń, 2009; Cempiel et al., 2014).

The average content of lithogenic elements, such as aluminium, barium, calcium, cobalt, magnesium, nickel, sulphur, strontium, titanium and vanadium in alluvial muds of the drainage basin is about twice as high as the geochemical baseline value in sediments of the Silesia-Cracow region (Tab. 4).

Accumulation of cadmium (up to 14 mg/kg), chromium (up to 320 mg/kg), copper (up to 130 mg/kg), lead (up to 1,500 mg/kg) and zinc (up to 4,700 mg/kg) in the Bytomka River sediments is probably associated with leachate from historical sludge dumps of smelters located between the river valley and the facilities of the Zygmunt smelter. These are sludge dumps of the historical Marien Wunsch zinc smelter and a zinc-processing plant of the former Zygmunt smelter (Degenhardt, 1870; Szczech, 2003; Zamet...,).

The Bytomka also receives material from water reservoirs which are strongly contaminated by metals and arsenic and connected by a stream flowing from the Lipiny quarter of Świętochłowice. The highest concentrations of silver (45 mg/kg), arsenic (1,320 mg/kg), cadmium (170 mg/kg), copper (314 mg/kg), manganese (2,400 mg/kg), nickel (70 mg/kg), lead (12,100 mg/kg), zinc (45,360 mg/kg) and iron (10%) have been recorded in sediments of the Ajska reservoir, located at the end of Lotnicza Street in Świętochłowice. It is an area of sludge dump (named Kopyto) of a historical zinc smelter (Dawid smelter, later renamed to Guidotto) to which zinc ore was transported from Szarlej near Bytom (Chropaczów...). In the 1920s, it supplied about 10% of domestic zinc production, and produced also sulphuric acid, nitrate, manganese and cadmium. In the 1930s, the smelter finished its activity. Until the recent time, part of the Lipiny sludge dump has been preserved. After 100 years, the waste still pollutes the sediments and water of the area.

Through the Rów Graniczny Stream, the Bytomka River is recharged and contaminated by the water that transport sediments from the area of the Żabie Doły nature-landscape complex, where zinc and lead ore-processing waste was disposed of (Cempiel et al., 2014).

Potok Bielszowicki (Kochłówka) Stream and its catchment. Hard coal mining operations in the Pokój and Halemba-Wirek mines have resulted in the disturbance of hydrogeological conditions in the drainage basin of the stream, leading to periodic floods.

In the analysed reach of the stream, alluvial deposits are contaminated by barium (up to 550 mg/kg), cobalt and nickel (up to 175 and 160 mg/kg, respectively), chromium (up to 190 mg/kg), copper (up to 170 mg/kg), manganese (up to 16,600 mg/kg), lead (up to 370 mg/kg) and zinc (up to 1,820 mg/kg). There are also enrichments in calcium (up to 12%), iron (up to 11.50%) and phosphorus (up to 1%) in this area.

The most polluted sediments come from a non-engineered channel of the stream (downstream of an unnamed tributary dewatering a waste dump area of the Halemba-Wirek coal mine), but earlier they were probably accumulated in a few marshlands in the valley and may have been transported down the stream during high water levels.

The main source of sediment contamination by metals is probably the activity of the currently closed down Batory Steelworks located in the upper part of the drainage basin. It operated for over 100 years, and the environment has been polluted due to the storage of raw materials and industrial waste and sewage. Since 1873, the smelter produced steel pipes and sheets under the name of Bismarckhütte (Huta Batory...). In the period 1912–1915, missiles, ship boilers and armour plates were produced here, and in subsequent years, steel, metal sheets and mining machines were manufactured. Redeployment of production lines required the use of many raw materials. This influenced the composition of wastewater and sewage. The contaminants in the Potok Bielszowicki sediments are also derived from leachate of the Halemba-Wirek mine heap and industrial effluents from the mine.

Rawa River and its catchment. Because of the engineering and covering of the Rawa River channel, most of sediment samples were collected downstream of the Klimzowiec sewage treatment plant located on the border of Katowice and Chorzów. Despite modernization and multi-stage sewage treatment, the sediments have proved to be highly contaminated with metals; most of them are industrial sludge. Their composition reflects the long-standing discharge of sewage from plants (mainly smelters) that no longer exist or have changed their type of production. The chemical composition of the aqueous sediments is also affected by pollutants currently introduced along with municipal and industrial sewage from Świętochłowice and Chorzów.

In the Rawa sediments, the maximum concentration of silver is 11 mg/kg, arsenic 222 mg/kg, cadmium 43 mg/kg, chromium 417 mg/kg, copper 266 mg/kg, iron 17.80%, mercury 4.35 mg/kg, manganese 18,790 mg/kg, nickel 213 mg/kg, lead 430 mg/kg and zinc 2,310 mg/kg.

Within the drainage basin, there are very highly polluted sediments of a no-name watercourse that drains the area between Żeliwna Street and a railway siding (including an area of old waste pile) in Katowice. The following concentrations were measured here: 17 mg/kg of silver, 350 mg/kg cobalt, 220 mg/kg chromium, 180 mg/kg copper, 2–3% iron, 4 mg/kg mercury, 590 mg/kg lead and 2,300 mg/kg zinc. The composition of the sediments indicates that the elements originate from drainage of a pile where post-smelting waste was disposed of (maybe from the nearby, currently inactive Baildon Steelworks).

Stagnant water reservoires. In the Rawa River valley, on the outskirts of the Osiedle Tysiąclecia residential area of Katowice, there are two water bodies called **Maroko** pond. The sediments of the larger one are more contaminated by metals. It was formed in a mine excavation as a result of coal extraction in the Kleofas mine. It once played a role of water recreation centre, but currently it is an ecological site and a breeding area for many animal species (including birds). Its water provide a number of fish species. However, it is worrying that its sediments (especially near the southern shore) contain high amounts of metals. The following concentrations were measured here: up to 12 mg/kg of silver, 480 mg/kg arsenic, 413 mg/kg cadmium, 405 mg/kg chromium, 1,399 mg/kg copper, 1.51 mg/kg mercury, 116 mg/kg molybdenum, 580 mg/kg nickel, 1,835 mg/kg lead, 103 mg/kg tin, 320–400 mg/kg strontium, 1,010 mg/kg titanium, 210 mg/kg vanadium and 3,130 mg/kg zinc.

Between the stadium of Ruch Chorzów sports club and the Rawa valley, there is a water body (cooling water settling pond) of the inactive Batory Steelworks in Chorzów. Its sediments are conspicuous by a particularly high content of iron, up to 34.40%, and elevated amounts of molybdenum (200 mg/kg), nickel (681 mg/kg), tin (132 mg/kg) and copper (2,420 mg/kg). The sediments are also contaminated by silver (12 mg/kg), cadmium (22 mg/kg), cobalt (51 mg/kg), chromium (901 mg/kg), mercury (1.08 mg/kg), lead (730 mg/kg) and zinc (3,640 mg/kg).

Sediments of a water body located close to the Zgoda Park and the former Florian Steelworks (currently MittalSteel) in Krauzego Street in Świętochłowice have been polluted likely by sewage discharged from the plant which was established in the 1830s (Florian Steelworks...). In the mid-1990s, the steelwork was closed down and currently the plant produces zinc-coated and varnish-coated metal sheets. Sludge in the settling tank contains 400 mg/kg of barium, 6.69% calcium, 256 mg/kg chromium, 145 mg/kg copper, 4.96% iron, 490 mg/kg lead, 0.246% sulphur, 13 mg/kg tin, 580 mg/kg titanium, and 1,800 mg/kg zinc.

In the Rawa River drainage basin there is also **Kalina pond** which has formed in a depression above a coal seam extracted from a shallow depth. The reservoir existed already before World War I and was used as a bathing site. Contamination of its surroundings dates back to the 19th century when the Bismarckhütte (later renamed to Batory) smelter and a tar distillery started their activity. For the last 50 years, the nearby located Hajduki (currently San Marco Polonia) chemical plant has produced paints and varnishes (Wantuch, Cudak, 2009). Wastewater was discharged into the reservoir, and there was also an industrial waste pile located nearby. Sediments of the pond are moderately contaminated by metals. The concentration of chromium is up to 40 mg/kg, copper 70 mg/kg, mercury 0.61 mg/kg, lead

310 mg/kg and zinc 1,050 mg/kg. Hazardous are phenols and other organic compounds accumulated in the reservoir. Currently, special measures are undertaken to decontaminate the water and sediments of the pond.

The name **Stawy Magiera** refers to two ponds located in Świętochłowice near the Drogowa Trasa Średnicowa diametral highway. The larger one (western) is also sometimes called Zacisze pond. It is connected by a canal with the more polluted eastern pond (called Matylda). Worth noting is the presence of cadmium (103 mg/kg), lead (425 mg/kg) and zinc (4,040 mg/kg) in this pond sediments.

Near the western border of Świętochłowice is **Martyn pond**, located just north of a municipal waste dump. Sediments of the pond, are underlain by glacial tills, and their composition shows a favourable predominance of lithological factors over anthropogenic ones. These sediments are abundant in aluminium (0.6–0.9%), iron (2.50–7.40%), magnesium (0.40–4.20%) and manganese (640–8,500 mg/kg). The content of other components in the sediments of the pond is probably due to the influence of leachate from a nearby landfill. This is evidenced by significant concentrations of anthropogenic elements. The following concentrations have been recorded: 98 mg/kg of arsenic, 605 mg/kg chromium, 120 mg/kg copper, 0.15 mg/kg mercury, 84 mg/kg nickel, 900 mg/kg lead and 2,600 mg/kg zinc.

Zojra pond, located in the area of Świętochłowice, developed as a result of land subsidence due to coal mining activity. It adjoins a mine heap composed also of slag from iron smelting. Pollution of sediments by metals in this pond can be associated predominantly with the storage of slag waste. They contain 515 mg/kg of arsenic, 905.9 mg/kg cadmium, 188 mg/kg copper, 11.80 mg/kg mercury, 7,200 mg/kg lead, 23 mg/kg tin, and 9,700 mg/kg zinc.

A cluster of ponds, located between industrial areas of the Pokój Steelworks and the Florian Steelworks in Ruda Śląska (in Stalowa Street), adjoins on the north a municipal waste dump. The amount of metals found in the sediments unequivocally indicates their origin from wastewater and slime discharged by smelters. The maximum concentrations are as follows: 900–1,104 mg/kg of barium, 10.14% calcium, 19.2 mg/kg cadmium, 170 mg/kg chromium, 340 mg/kg copper, 15.13% iron, 0.70 mg/kg mercury, 1.80% magnesium, 32,300 mg/kg manganese, 1,400 mg/kg lead, 58 mg/kg tin, 400–510 mg/kg strontium, 530 mg/kg titanium, 110 mg/kg vanadium, and 4,700 mg/kg zinc.

Staw Marcina pond, located between the Ruda Chebzie railway station and the former Silesia Steelworks, is a typical sinkhole reservoir. In its neighbourhoods are located dumps of post-mining waste, slag and concrete fragments, so its sediments are abundant in metals: 172 mg/kg of copper, 103 mg/kg nickel, 380 mg/kg lead, 1,050 mg/kg zinc and 6.91% iron.

A cluster of a few water reservoirs on the border of Bytom and Chorzów – called **Żabie Doły** – was formed as a result of mining operations. On the surface and in the shallow subsurface under a cover of Neogene deposits there are Triassic ore-bearing dolomites containing zinc and lead ores (Wyczółkowski, 1957). They have been mined and processed already since the 12^{th} century, and the ore mining has been accompanied by the development of ore tailing piles and mining sinkholes. Since about 1860, the Biały Szarlej zinc and lead mine has been operated beyond the northern boundary of the map sheet area, later transformed at its final stage of activity (in 1989) into a metallurgical complex of Zakłady Górniczo-Hutnicze (ZGH) Orzeł Biały (Machowski, 2010). The largest tailing pile of the ZGH Orzeł Biały is located north of the Żabie Doły ponds. Other old zinc-lead ore waste dumps are dispersed throughout the area and currently hardly visible in the field, but they significantly contaminate the environment.

Since the 1920s, the first reservoirs were used as settling ponds for tailings of active metallurgical plants, and waste dumps existed in the immediate neighbourhood. Other ponds were formed in the 1950s. In the past, the ponds were separated by railway embankments. The anomalous concentration of metals may also origin partly from geological sources. Rocks, exposed over centuries, have been eroded and the products of their weathering have migrated into the sediments.

The concentration of heavy metals in aqueous sediments of these ponds is variable. The maximum values were measured in sediments of the south-western pond, where the concentration of silver is 7 mg/kg, arsenic 171 mg/kg, barium 650 mg/kg, cadmium 150 mg/kg, copper 160 mg/kg, iron 4.42%, manganese 2,420 mg/kg, lead 5,100 mg/kg, sulphur 1.860% and zinc 28,522 mg/kg.

Similar metal concentrations are noted in a no-name reservoir of nearby Maciejkowice with 21 mg/kg of silver, 390 mg/kg arsenic, 230 mg/kg cadmium, 307 mg/kg copper, 1.51 mg/kg mercury, 25,080 mg/kg lead and 28,500 mg/kg zinc. Probably, this pond was also a storage site of zinc and lead ore tailings.

In the Lipiny quarter of Świętochłowice, there is a string of small ponds connected by the small stream. In all of these ponds the sediments are polluted by metals, but the greatest concentrations are found in **Gliniok pond**. Sediments of this pond contain 103 mg/kg of silver, 2,220 mg/kg arsenic, 98 mg/kg cadmium, 5,800 mg/kg lead and 30,721 mg/kg zinc.

Sediments of **Ajska** pond (at the end of Lotnicza Street in Świętochłowice) contain 45 mg/kg of silver, 1,320 mg/kg arsenic, 170 mg/kg cadmium, 314 mg/kg copper, 12,100 mg/kg lead, 45,360 mg/kg zinc and about 10% of iron. This is an area of the Dawid zinc smelter established in 1823, and its successor, the Guidotto smelter (Chropaczów...).

Water reservoirs in the area of WPKiW culture and recreation park. Sediments of most of the small ponds located in the area of WPKiW show concentrations of the analysed elements falling within the limits of natural geochemical background values. However, some of them reveal elevated concentrations of lead (up to 200–300 mg/kg) and zinc (up to 1,600 mg/kg).

Other water reservoirs. Sediments of the smaller ponds which are located in the upper part of the Rawa drainage basin contain most of metals as well as sulphur, phosphorus and arsenic at the concentrations close to the regional geochemical baseline value. However, like in many other reservoirs and watercourses, they contain lead (up to 220 mg/kg) and zinc (up to 1,350 mg/kg). Elevated concentrations of barium (260–380 mg/kg) can be linked with a lithological source represented by outcrops of Carboniferous clastic rocks enriched with this element. The least contaminated sediments are found in Skałka pond.

SURFACE WATER

Human impact on water resources has a quantitative (a change in hydrologic regime), qualitative (water pollution, changes in chemical composition) and morphological (transformation of watercourse channels and lake basins) significance. Unfavourable changes result in ecological effects involving the disturbance of habitat conditions, regression of certain species, and reduction in biodiversity (Bańkowska...).

The studies of surface water conducted in the Bytomka River, Potok Bielszowicki Stream (Kochłówka) and Rawa River drainage basins were focused only on their chemical composition. In order to compare and easier evaluation of the quality of the analysed water, provided are the contents of their individual components and the results of calculated statistical parameters along with the threshold values of surface water quality indices used in Poland (Rozporządzenie..., 2011), and indices for mineral and drinking water in accordance with UE recommendations (EU Directive 1998/83/EC; EU Directive 2009/54/EC) – Tab. 5.

The pH values of the water in watercourses and stagnant water reservoirs in the map sheet area do not exceed normative recommendations. Their mineralization, indicated by EC values, mostly exceeds 1.5 mS/cm, which is approved as a boundary limit for good quality water (Witczak, Adamczyk, 1994; Rozporządzenie..., 2011). Unsatisfactory water quality is due to discharges of coal mine water, municipal sewage and industrial wastewater from metallurgical plants.

Bytomka River and its catchment. The water of Bytomka River is characterised by alkaline pH (8.0–8.4), whereas in its drainage basin the values range between 6.7 and 9.6.

The electrolytic conductivity of the water in the drainage basin is highly variable, ranging from 0.37 to 10.94 mS/cm, and the median value of EC in the Bytomka River water is 6.80 mS/cm, proving their strong mineralization due to the influx of mine water and municipal sewage. Beyond the northern boundary of the map sheet, the river receives sewage from a sewage treatment plant in Bytom (in Małgorzatki Street) and from the Orzegów sewage treatment plant located in the river's lower reach. The salts originate also from surface runoff from the Bytom Główny railway station area, and from dewatering of facilities of the closed-down Szombierki coal mine.

The Bytomka River water is contaminated predominantly by a number of constituents that originate from mine water, including: boron (up to 1.92 mg/dm^3), potassium (up to 48.3 mg/dm^3), lithium (up to 212.9 µg/dm^3), sodium (up to 1,442.5 mg/dm^3) and sulphates (up to 13,015 mg/dm^3). They are also abundant in magnesium and calcium that come from the same sources; however the concentrations of arsenic (5 µg/dm^3) and barium (0.03–0.05 mg/dm^3) are relatively low.

The Bytomka River is recharged and contaminated by a stream that flows through a few stagnant water reservoirs in the north-western part of Świętochłowice. High concentrations of arsenic (21 µg/dm^3) and metals found in some of the reservoirs (8.89 µg/dm^3 cadmium, 4.13 µg/dm^3 copper, 1.84 µg/dm^3 antimony, 2–5 mg/dm^3 zinc, up to 10 µg/dm^3 selenium and 0.80 µg/dm^3 thallium) are probably due to weathering and washing out of a tailings heap of the historical Guidotto smelter. The water of these reservoirs is also polluted by components characteristic of mine water, including boron, sodium, potassium, lithium and sulphates. The stream also receives municipal sewage from Chropaczów (a quarter of Świętochłowice), which can be an additional source of contaminants in the Bytomka River water. This is evidenced by the presence of phosphorus up to 0.40 mg/dm^3, and by the previous water quality analyses that showed high concentrations of sulphates (1,800 mg/dm^3) and nitrates (Działoszyńska-Wawrzkiewicz, 2007).

In the stagnant water bodies of the left-bank side area of the Bytomka drainage basin the EC value is >6 mS/cm, and there are considerable amounts of metals up to 1 µg/dm^3 of cadmium, up to 15 μg/dm^3 cobalt, 2–4 mg/dm^3 manganese, 10–15 μg/dm^3 molybdenum, 10–12 μg/dm^3 nickel and 2.26 μg/dm^3 antimony. They can origin from the electroplating factory.

Because of the high values of electrolytic conductivity, as well as high calcium, magnesium and sulphate concentrations, most of the analysed water of the Bytomka River is classified as substandard water.

Potok Bielszowicki (Kochłówka) Stream and its catchment. The stream is characterised by high flow rates caused by the transfer of water from other drainage basins in order to supply the population and industry with water, and by pumping out of mine water from the Pokój and Halemba-Wirek coal mines (Cudak et al., 2009).

The electrolytic conductivity values measured in the surface water indicate its extremely high contamination (average EC is 9.54 mS/cm), while the EC values above 1 mS/cm prove an excessive mineralization (Witczak, Adamczyk, 1994). The stream water contains high concentrations of constituents of saline water from coal mines, including potassium (up to 68.7 mg/dm^3), lithium (up to 555.8 μg/dm^3), magnesium (up to 228.4 mg/dm^3), sodium (up to 2,112.1 mg/dm^3), sulphates (up to15,750 mg/dm^3) and strontium (up to 3.250 mg/dm^3).

Discharges of industrial wastewater from the Batory Steelworks, leachate from its waste dumps and storage sites of raw materials are in turn the cause of excessive concentrations of metals, especially in the upper part of the drainage basin. Significant concentrations of cobalt (up to 4 μg/dm^3), molybdenum (up to 14,88 μg/dm^3) and nickel (10–11 μg/dm^3) have been found in this area.

The beneficial fact is the small amount of thallium and cadmium (<0.05 μg/dm^3). Along the entire reach of the stream the contents of other elements are uniform.

The high values of electrolytic conductivity and concentrations of calcium, magnesium and sulphates allow for categorising the stream waters as substandard.

Rawa River and its catchment. The Rawa River water is characterised by the electrolytic conductivity values in the range of 0.76–3.63 mS/cm and the pH values of 8.5–9.6. It is contaminated by metals originating probably from discharges of industrial wastewater from the Silesia, Florian and Batory steelworks, and from leachate of their tailing heaps. The water show elevated concentrations of cobalt (up to 5.92 μg/dm^3), iron (up to 4.36 mg/dm^3), manganese (up to 3 mg/dm^3), molybdenum (up to 5.09 μg/dm^3), nickel (up to 11.8 μg/dm^3), antimony (up to 1.18 μg/dm^3) and thallium (up to 0.29 μg/dm^3). Discharges of mine water into the Rawa River are evidenced by high concentrations of potassium, lithium, sodium and sulphates. Downstream of the Klimzowiec sewage treatment plant, the poor water quality in the river is additionally worsened by the presence of phosphorus (>0.5 mg/dm^3) and sulphates (> 3,330 mg/dm^3).

The Rawa water is classified as substandard water due to the exceeded permissible limits for electolytic conductivity, as well as high phosphorus and sulphate concentrations.

Stagnant water reservoirs. Maroko pond is recharged by inflows from stormwater drainage systems of nearby residential areas, but there is also fish restocking on a regular basis, and the pond is a habitat to many animal species. The pH of its water is 8.8–9.0 and the EC value is 0.590–0.640 mS/cm. The analysed parameters meet the standard for surface water quality class I. Permissible concentrations are exceeded only in the case of sulphates that occur in the amount of 380–404 mg/dm^3.

The water of a **tailings pond of the Batory Steelworks** in Chorzów is characterised by the pH value of 8.9 and EC value of 0.523 mS/cm. It is substandard water because of high concentrations of molybdenum (68.97 µg/dm^3), nickel (48.8 µg /dm^3), antimony (4.28 µg /dm^3) and sulphates (766 mg/dm^3).

Kalina pond contains mineralized water (EC 3.670–3.900 mS/cm) which are alkaline (pH 8.2–8.5). They are contaminated by both metals (125.7 µg/dm^3 of aluminium, 0.21 µg/dm^3 cadmium, 0.60 mg/dm^3 iron, 0.933 mg/dm^3 manganese) and other constituents (14.5 µg/dm^3 arsenic, 0.371 mg/dm^3 phosphorus, 12,450 mg/dm^3 sulphates, and 20.73 mg/dm^3 silica). The distinctive feature of the water is the presence of elements that can originate from wastewater of the chemical industry, which include: beryllium (0.10–0.12 µg/dm^3), chromium (0.02 µg/dm^3), nickel (10 µg/dm^3), selenium (5 µg/dm^3), lead (3.02 µg/dm^3), titanium (0.026 mg/dm^3), vanadium (65–88 µg /dm^3) and phosphorus (0.30–0.40 mg/dm^3).

The water of the **Magiera ponds** show the pH values in the range of 7.7–8.1 and the EC values from 1.865 to 2.090 mS/cm. Because of the high concentrations of sulphates (up to 8.025 mg/dm^3) the water has been categorised into substandard water, although the concentrations of metals (up to 189.5 mg/dm^3 of calcium, up to 80 mg/dm^3 magnesium, up to 18.2 µg/dm^3 nickel, and up to 7.02 µg/dm^3 antimony) fall into water quality class II.

The water of **Zojra** pond is characterised by elevated concentrations of calcium (196.4 mg/dm^3), magnesium (100 mg/dm^3), silica (18.6 mg/dm^3) and uranium (4.1 µg/dm^3), and it is also contaminated by sulphates (7,062 mg/dm^3).

A number of water reservoirs located between the industrial area of the Pokój and Florian steelworks in Ruda Śląska (in Stalowa Street) contain alkaline water (pH 8.4–8.7) with the electrolytic conductivity values ranging from 2.540 to 2.700 mS/cm. It is contaminated mainly by an assemblage of elements typical of mine water (8,972 mg/dm^3 of sulphates, 201.7 mg/dm^3 potassium, 302.3 μg/dm^3 lithium, 1.6 mg/dm^3 boron). In addition, the water is abundant in elements that come from wastewater of the metallurgical industry: cobalt (2–3 μg/dm^3), nickel (4–7 μg/dm^3), vanadium (5–7 μg/dm^3), molybdenum (30 μg/dm^3), antimony (2–3 μg/dm^3), selenium (3–4 μg/dm^3) and thallium (0.2–0.3 μg/dm^3).

The water of **Ajska** pond have pH of 9.1 and EC of 2.860 mS/cm. It is substandard water due to strong pollution by sulphates (15,114 mg/dm^3) and the presence of calcium (215.4 mg/dm^3) and magnesium (240.7 mg/dm^3).

The water of **the Żabie Doły** ponds is characterised by the pH values in the range of 7–8 and EC values >1 mS/cm, indicating considerable mineralization. The concentrations of metals are highly variable. Cadmium, chromium and thallium occur at concentrations below the determination limit of the analytical method. Contamination by lead and zinc is insignificant. Instead, there is enrichment in cobalt (up to 1 μg/dm^3), copper (up to 1.15 μg/dm^3) and antimony (4–5 μg/dm^3). The water also contains increased amounts of constituents that originate from mine water: boron, potassium, lithium, sodium, rubidium, sulphate, strontium and uranium. It is substandard water because of the elevated concentrations of sulphates (1,790–6,480 mg/dm^3), barium (up to 0.660 mg/dm^3) and nickel (72.2 μg/dm^3).

Other water reservoirs. The water of other closed water bodies in the upper part of the Rawa drainage basin and in the area of WPKiW culture and recreation park show a similar pH value, most frequently of 8–9. The EC values of the water between these two areas are quite different. In the WPKiW area it is below 0.5 mS/cm, proving low mineralization, and in the western part of the drainage basin it commonly exceeds 2 mS/cm, attaining a level of 6.03 mS/cm. The contents of elements in the individual water bodies point to their different origins.

In the WPKiW area, the water of reservoirs and watercourses is characterised by low concentrations of all analysed constituents, excluding sulphates whose concentrations vary between 400 and 1,400 mg/dm^3, which does not allow for classifying it as good quality water.

CONCLUSIONS

1. Anthropogenic pollution sources in the natural environment include: metallurgy of iron and non-ferrous metals, chemical and metal industries, mining of coal and its large-scale burning in power plants, historical exploitation and smelting of zinc and lead ores, the impact of industrial waste (heaps of gangue and slag, settling ponds for sludge coal mud, mine water discharges), urbanization and transport.

2. The chemical composition of soils has been highly altered by anthropogenic factors in relation to the parent rocks to such a degree that the basic geochemical features of rocks are difficult to decipher. Natural components of soils have been mixed with foreign materials, often repeatedly digged, soaked with saline water from coal mines, and desiccated.

3. The distribution of elemental concentrations in soils (aluminium, barium, calcium, cobalt, magnesium, manganese, nickel, phosphorus, strontium, sulphur, titanium and vanadium), whose main source is the parent rock, is controlled by the type of industrial activity in particular areas rather than by the geological structure of bedrock. A clear relationship between the chemical composition of bedrock and soils is marked only in areas of Triassic carbonate outcrops, where the soils are rich in calcium, magnesium, iron and manganese.

4. The soil pH is poorly diverse and depends primarily on the land use type. In both soil depth intervals, alkaline soils predominate, which occupy larger areas in the subsoil (0.8–1.0 m). Their alkalization is caused by the precipitation of particulate matter, mainly from coal burning in the electricity and heating sectors and other industries.

5. In areas of historical mining of zinc and lead, around inactive and active metal smelters and near heaps and dumps, there are numerous anthropogenic anomalies of silver, arsenic, cadmium, chromium, copper, iron, mercury, nickel, lead and zinc. The most contaminated soils with these metals are found in the north-western quarters of Świętochłowice, eastern areas of Ruda Śląska and on the border of Bytom and Chorzów.

6. The contamination of sediments and surface water is anthropogenic in nature. It originates from the discharge of mine water of active and inactive coal mines, and industrial and municipal sewage, as well as from the drainage of mine waste and tailings dumps.

7. Most of sediments of the watercourses and stagnant water reservoirs are heavily contaminated by metals derived from contemporary and historical metallurgy of steel and non-ferrous metals and from the activity of metallurgical plants (chromium, zinc, cadmium, cobalt, copper, nickel, lead, mercury, silver and iron).

8. The tested water is mostly alkaline. Considerable salinity of most of the watercourses is associated with wastewater discharges of mineralized mine water. The water discharged from coal mines result mainly in the strong contamination of watercourses and stagnant water reservoirs by sulphate, boron, potassium, lithium, sodium, strontium, thallium and antimony. The water of streams draining areas of waste dumps is contaminated by arsenic, barium, copper, iron, manganese, molybdenum, phosphorus and antimony.

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