Szczegółowa mapa geochemiczna Górnego Śląska

Detailed geochemical map of Upper Silesia

1:25 000

Arkusz
Sheet **TARNOWSKIE GÓRY**

Redakcja
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Państwowy Instytut Geologiczny
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INTRODUCTION

Geochemical mapping at the scale of 1 : 25,000 for the map sheet Tarnowskie Góry M-34-50-D-a is a continuation of detailed mapping work initiated in 1996–1999 by the pilot sheet 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. In the period 2017–2021, the work was continued as another tranche of four map sheets, including the Tarnowskie Góry region.

The southeastern part of the map sheet area covers the town of Tarnowskie Góry, located in the central part of the Silesian Voivodeship. The history of the town is associated with the mining of silver, lead and zinc ores, which was developing most intensely from the 17th to 19th century, and ended at the beginning of the 20th century when the ore resources became exhausted. The plants associated with ore mining have been closed down, and the preserved post-mining facilities of historic value have been inscribed on the UNESCO World Heritage List in 2017. The most valuable is the Historic Silver Mine, which includes the excavations of the historical Fryderyk ore mine and a section of one of the tunnels that drained it, called the Black Trout Adit. The 19th-century flotation tailings dumps of the Fryderyk mine at Długa Street in Tarnowskie Góry and in Bobrowniki Śląskie-Piekary Rudne in the Kunszt Park, are also of historic value (Pawlak, Filak, 2017).

The main ecological problem of the town is the hazardous waste landfill of the former Chemical Plant (ZCH) Tarnowskie Góry and the waste dumps that remained after ore mining, dispersed in many places, from which metals, arsenic and sulfur penetrate into the ground and water (Lis, Pasieczna, 1995a, b, 1997).

The results of geochemical studies within the area covered by the Tarnowskie Góry map sheet, presented in a cartographic form with an extensive commentary text and tabular summaries, show the current quality status of soils, sediments of watercourses and reservoirs, and surface waters, as well as comparison to the natural regional background and applicable legal norms.

The collected information may be useful in giving opinions on local spatial development plans, conducting proceedings related to issuing decisions on environmental conditions and water law permits, assessing threats to the soil and water environment, and fulfilling the obligation imposed on the *starosts* by the Environmental Protection Law, i.e. conducting periodic quality tests of soils as part of state monitoring.

The geochemical data from the study should also be used in the preparation of registers of historical pollution maintained by the General Directorate for Environmental Protection (in accordance with the EPL Act) and in conducting Environmental Impact Assessments (in particular for the cumulative impact assessment).

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

The following persons participated in the implementation of the study:

- **A. Pasieczna** – research concept and project;
- **A. Konon** – supervision and coordination;
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- **M. Białecka, E. Kałwa –** chemical processing of samples for analysis;
- **J. Gąsior, B. Kamińska, M. Stasiuk –** organic carbon content determination using high-temperature combustion with IR detection;
- **M. Bellok, M. Białecka, E. Kałwa, A. Maksymowicz –** pH determination;
- **J. Duszyński, E. Górecka, D. Karmasz, D. Lech –** Hg content determination using the CV-AAS method;
- **W. Bureć-Drewniak, J. Kucharzyk, D. Karmasz, D. Lech, J. Retka –** determination of contents of major and trace elements using the ICP-OES and ICP-MS methods;
- **M. Cyglicki, A. Grabowska, A. Ilska, K. Szewczuk, A. Trojanowska** – grain-size analysis;
- **A. Konon, A. Pasieczna** – statistical calculations;
- **K. Bala, A. Konon, A. Pasieczna, A. Szczypczyk** – compilation of geochemical maps;
- **A. Pasieczna** – text preparation.

CHARACTERISTICS OF THE MAP SHEET AREA

Geographic and administrative location. The area covered by the Tarnowskie Góry M-34-50-D-a map sheet is located mostly in the Silesian Upland within the lower-order unit called the Tarnowskie Góry Ridge, and partially in the Silesian Lowland within the lower-order unit of the Opole Plain (Kondracki, 2009).

Within the study area, there are the districts of Tarnowskie Góry (towns with poviat rights): Strzybnica, Rybna, Opatowice, Śródmieście-Centrum, Stare Tarnowice, Repty Śląskie, Osada Jana, Bobrowniki Śląskie-Piekary Rudne and Sowice, and parts of the Lasowice and Pniowiec districts. The northern portion of the map sheet area in the Tworóg commune and its western part in the Zbrosławice commune belong to the Tarnowskie Góry poviat (Pls. 1–63).

Topography, geomorphology, hydrography. The ground surface in the map sheet descends towards the northwest (from 327 m a.s.l. on the hill between the PKP residential area and Repecka Street in Tarnowskie Góry to 254 m a.s.l. in the lower sector of the Stoła River valley). The Stoła River (a tributary of the Mała Panew River) flows across its central part; the northern part is drained by the Pniowiec Stream (a tributary of the Stoła River), and the southern part is drained by the Drama River (a tributary of the Kłodnica River), belonging to the Odra drainage basin.

In the southern and eastern parts of the study area, the hilly relief is strongly transformed as a result of centuries-long mining of Zn-Pb ores, and now difficult to restore. Its characteristic feature is numerous forms of post-mining landscape: heaps, humps, embankments and ditches, circular troughs of pre-existing excavations, and funnel-shaped depressions of old shafts. The northern, flatter part of the area is covered with forests.

Build-up area and land use. The land use and housing area type differ between the particular regions of the study area: most of the area is represented by agricultural land (arable fields, meadows) and forests (Pls. 2–3) that cover 38% and 33% of the map sheet area, respectively. About 17% of the area is occupied by urban development (housing estates, services and trade), 7% by rural housing, and 4% by industrial areas. The urban-industrial areas occur mainly in the southeastern part of the map sheet area. In the eastern part, there is the largest railway goods station in Poland (8.5 km long).

Other types of land use are road green belts, lawns and town parks, allotment gardens, water reservoirs, and railway areas.

Economy. In the southeastern part of Tarnowskie Góry (in the districts of Bobrowniki Śląskie-Piekary Rudne, Śródmieście-Centrum, Repty Śląskie and Stare Tarnowice), Zn-Pb ore deposits were mined for several centuries. Mining operations were conducted here from the early Middle Ages, exploiting surface ores (Nowak, 1927; Grzechnik, 1978), until 1933, when the deposits extracted from considerable depths were also considered exhausted and the 800-year history of mining in Tarnowskie Góry came to an end (Jendruś, 2015). In the mid-16th century, the extraction covered mainly seams occurring at a depth of 30–40 m below the ground surface. A network of mine drifts and drainage tunnels was thereby created.

The earliest exploitation focused mainly on the extraction of silver-bearing galena. In the 19th and 20th centuries, calamine, limonite and dolomite (Tarnowskie Góry...) were also mined. The Zn-Pb ores that were mined in Bobrowniki Śląskie in the Fryderyk mine in the years 1786–1862 were smelted at the Fryderyk smelter (in Strzybnica), obtaining silver and lead. In the period 1863–1886, the ore processing technology was modernized to obtain zinc as well (Huta Fryderyk…). The smelter was closed in 1937, and after World War II, a cast iron foundry was opened in its place, later transformed into the Strzybnica Metal Works, and then into the Zakłady Mechaniczne Przemysłu Metali Nieżelaznych Zamet (Zamet Mechanical Plant of Non-ferrous Metals Industry).

In the 13th–14th centuries, mining was carried out near Sucha Góra and Srebrna Góra. From the beginning of the 16th century, the deposits located between Repty and Tarnowice and in Lasowice were of interest. In the mid-16th century, Tarnowskie Góry was one of the largest Zn-Pb ore mining centres in Europe (Piernikarczyk, 1984). Intensive exploitation lasted about 90 years, but the mining shafts were not deep and situated close to each other (Nowak, 1927). At the beginning of the 17th century, the mining fell into decline due to difficulties with drainage of workings (Molenda, 1960, 1972), and the next stage of ore extraction involves the use of a drainage system for deeper parts of the deposits, using tunnels and pump stations (Piernikarczyk 1926, 1933). This more modern method of drainage was applied in the Fryderyk mine, which operated in the years 1784–1910. This exploitation resulted in the formation of approx. 185 km of corridor workings, chambers and tunnels, and approx. 20,000 shafts (Jendruś, 2015).

In 1924–1925, the Tarnowskie Góry Chemical Plant (ZCH Tarnowskie Góry) began operations in the place where silver and lead ores were previously mined, later aluminum-potassium alum and sulfuric acid were produced, an finally ironworks and a paper mill were built. The production at ZCH Tarnowskie Góry began with the production of lithopone (a white pigment, being a mixture of ZnS zinc sulfide and $BaSO_4$ barium sulfate).

In the following years, the company produced oil paints, varnishes, sodium dichromate, barium chloride, barium sulfide, barium nitrate, barium sulfate, boric acid, borax, aluminum sulfate, and copper sulfate. At later stages, the production of zinc oxide, zinc nitrate, zinc sulfate, sodium perborate, borax and boric acid was launched. After World War II, lithopone, strontium reagents, and compounds of barium, zinc and boron were produced.

Substances considered to be harmful were used (barite; acids: nitric, phosphoric, sulfuric, hydrochloric, oxalic; soda lye) in the production (Majer, 2004). The production of barium and boron compounds continued after World War II. After that activity, a hazardous waste landfill has been left, which is an ecological problem for the town. For many years of production, the waste was deposited in dumps around the plant, without any ground protection measures (Zakłady…, 2017).

Other important industrial plants in Tarnowskie Góry include: FASER emergency equipment and mining lamps factory, TAGOR machinery and equipment factory, CHEMET plants – the largest manufacturer of gas pressure tanks in Poland, ZAMET machine-building plants, EMA Electrocarbon – electrotechnical components factory, and electroplating and galvanizing plants.

GEOLOGY AND MINERAL DEPOSITS

The map sheet area is included in the northern part of the Upper Silesian Foredeep that is a vast trough filled with Devonian and Carboniferous rocks covered with Permian, Triassic, Neogene and Quaternary deposits (Buła, Kotas, eds., 1994). The southern part of the map sheet area belongs to the Upper Silesian Coal Basin (USCB, GZW in Polish), whereas the northern part is included in its margin (Jureczka *et al*., 2005).

The coal-bearing Upper **Carboniferous** basement is represented by the Malinowice Beds (Upper Visean – Namurian A). They are composed of coal-free clay-muddy rocks with interbeds of fine-grained sandstones.

The coal-bearing Upper Carboniferous rocks constitute the sandstone-mudstone-claystone complex of the Paralic Series of the Marginal Beds (Namurian A), characterized by sedimentary cyclicity (Jureczka *et al*., 2005). They are composed of sandstones and claystone-mudstone rocks with thin interbeds of coals, coal shales, and occasional sapropelic shales. These sediments were deposited under both terrestrial and nearshore conditions with periodic marine inundations, as evidenced by the presence of marine faunal fossils and numerous interbeds containing freshwater ones. The lower boundary of the series is defined by the top of the so-called Stur marine horizon (XVI), characterized by the accumulation of marine faunal fossils in clastic rocks, and the top boundary is marked by the base of hard coal seam 510. The maximum thickness of the Paralic Series, reaching 600 m, is found in the southwestern part of the map sheet area; the deposits wedge out northward and, near the town of Tarnowskie Góry, they mark the northern boundary of the USCB. In most of the sheet area, the Carboniferous deposits are covered with the Permian and locally with the Triassic.

Permian sandstones, conglomerates, claystones and mudstones fill a tectonic graben of the Tarnowskie Góry Trough. It belongs to a larger unit – the Sławków Graben that forms the northern and northeastern margin of the USCB (Siedlecka, 1964; Kiersnowski, 1991). The total thickness of the Permian molasse exceeds 500 m in the map sheet area. The Permian rocks in the area located east of Tarnowskie Góry are represented by mudstones with concntrations of pyrite, sandstones and marls passing into clay shales, covered with alternating series of conglomerates and sandstones. The conglomerates are composed of pebbles of Devonian limestones, quartzites, porphyries and melaphyres, and their cement contains tuffs (Żero, 1968). These deposits, previously included in the Rotliegend (Siedlecka, 1964), are referred to as the Bolesław Formation and included in the Zechstein (Kiersnowski, 1991). Lower Permian deposits (Sławków Formation) occur in patches in the Tarnowskie Góry Trough as isolated occurrences that have remained after a period of intense erosion.

Triassic rocks overlie the Carboniferous or Permian throughout the map area, forming small, fragmented outcrops in its central and southeastern parts (Pl. 1). The thickness of the Lower and Middle Triassic deposits is constrained by the tectonics and the relief of the surface of underlying rocks, reaching approx. 250 m in the northwestern part of the study area.

The Lower Triassic deposits are represented by sands, sandstones, clays, claystones and mudstones of the terrigenous Świerklaniec Beds that are not exposed on the surface in the map sheet. The Middle Triassic deposits, characteristic of the epicontinental facies, referred to as the Muschelkalk, build the hills in the central and southeastern parts of the map sheet area. The Middle Triassic succession begins with marine deposits, previously referred to as the Röt, represented by marly-dolomitic facies with a thickness of 30–50 m (Kotlicki, 1995). They are overlain by limestones (pelitic, wavy, dolomitic) comprising the Błotnica Beds and the Gogolin Beds. Their total thickness is in the range of 40–60 m, and outcrops are located on the slopes of hills in the southeastern part of the map sheet.

The Gogolin Beds are overlain by Zn-Pb ore-bearing dolomites, approx. 20–40 m in thickness. These are epigenetic rocks, formed as a result of the hydrothermal alteration of limestones, mainly of the Górażdże Beds, as well as of the Terebratula and Karchowice beds. The dolomites (minor limestones) are crystallized to varying degrees. They are characterized by strong fractures and the presence of irregular caverns, many filled with lead, zinc and iron minerals (galena, sphalerite, pyrite, marcasite). In the outcrops of ore-bearing dolomites, metal sulfides are oxidized and concentrated as calamines, often in association with iron ores (limonites).

Limestones and marls of the Górażdże, Terebratula and Karchowice beds, occurring in the section above the ore-bearing dolomites in the study area, have almost completely underwent metasomatosis and are part of the ore-bearing dolomites.

Diplopora dolomites (Jemielnica Beds) and dolomites and limestones of the Tarnowice Beds are exposed on the surface in the southern part of the map sheet area (Stare Tarnowice and Repty), whereas limestones, dolomites, clays, claystones, mudstones and shales (constituting the Rybnik, Boruszowice and Miedary beds) in its central part.

The **Neogene** deposits that outcrop in the Bobrowniki residential area (Pl. 1) reach a thickness of about 34 meters in borehole sections. They are composed of regoliths in karst sinkholes and chimneys that developed at the top of Triassic carbonate rocks, especially in the areas of outcrops of the Gogolin and Górażdże limestones. These are variegated loams, sands, muds and clays. Local accumulations of these deposits in the form of limonite ores, calamines and refractory clays were intensely exploited in the 19th century.

Quaternary deposits cover over 85% of the map sheet area; their extent and thickness increase northward (up to 40 m in the Stoła River fossil valley). These are Pleistocene glacial and weathered tills, glaciofluvial sands and gravels, as well as ice-dammed lake clays and muds. Sands, gravels, boulders and tills build up the hills extending in the southern and central parts of the map sheet area, forming a chain of terminal moraines that marked the ice-front stillstand zone during its maximum limit. The undivided Quaternary deposits are sands, silts and deluvial clays, not exceeding a few metres in thickness. In the northeastern part of the map area, within an extensive outwash plain, dunes and thin covers of aeolian sands overgrown with forests are common landforms. Holocene sediments are found only in the valleys of contemporary rivers. These are fluvial sands, gravels and muds of floodplain terraces, up to 8 m thick, alluvial muds of valley bottoms (sandy muds with a large amount of humic substance), 2–4 m thick, and occasional peats.

Mineral deposits. In the map sheet area, four mineral deposits have been documented: clays, loams, molding sands and backfilling sands (Szuflicki, ed., 2020). Information on the parameters of the deposits and quality parameters of minerals is given after geological documentations of individual deposits and the system of management and protection of mineral resources (MIDAS).

The deposits of **building ceramics raw materials**, several hectares in size, are represented by the Quaternary Bobrowniki tills deposit and the Middle Triassic Rybna clay deposit. The tills of the Bobrowniki deposit range from 2.8 to 12.7 m in thickness and occur on the ground surface or under the overburden of up to 3.2 m thick. The clays of the Rybna deposit, documented within two fields, vary in thickness from 5 m to 19 m and occur on the surface or under the overburden (0.4 m thick on average). The mineral deposit was mined from the beginnings until the 1960s. The raw material of good technological parameters was used in nearby brickyards for the production of bricks and thin-walled products. Ponds, mainly farmed, are the remains of numerous workings.

In the northern part of the map sheet, there are two fields of the Strzybnica **backfilling sand** deposit (preliminarily documented, category C_2) covering the area of approx. 629 ha. Directly on the ground surface or under a thin overburden (up to 1.0 m), there is a layer of quartz sands, up to 15 m thick. The resources are approximately 33.4 million m^3. Due to good parameters, the aggregate was used for decades as a backfilling material in hard coal mines. The deposit remains undeveloped.

In the southeastern part of the map sheet area, the Bobrowniki **molding sand** deposit has been documented, covering an area of approx. 4 ha. Under a thin overburden, there is a layer of sand and gravel aggregate, attaining a thickness of up to 10 m. The deposit is undeveloped.

The **zinc and lead ore** deposits are of historical significance (Molenda, 1960, 1972; Majorczyk, 1985, 1986). These depleted deposits were discovered in Triassic ore-bearing dolomites and were among the world's largest and richest Zn-Pb ore deposits (Szuwarzyński, 1996; Paulo, Strzelska-Smakowska, 2000). Currently, they are no longer listed in the national resource balance. The remains of the centuries-long exploitation of Zn-Pb ore-bearing dolomites include numerous post-mining heaps, most of them poorly marked in the terrain relief due to the passage of time.

HUMAN IMPACT

The environmental problems in the study area are a consequence of industrial (mainly historical) activities and, to a lesser extent, urbanization, which have led to changes in the landscape and hydrographic network and to pollution of the natural environment. In many places, the study area is heavily transformed as a result of mining and processing of Zn-Pb and iron ores, dating back to the early Middle Ages. This activity left behind shafts, drifts, underground workings, and heaps of flotation tailings. Degraded areas are being gradually reclaimed through afforestation and levelling of waste heaps. Hazardous waste from the chemical plant Zakłady Chemiczne (ZCH) Tarnowskie Góry is also being successively neutralized.

Atmospheric air. The main problem in the field of air pollution is related to emission due to the combustion of fuels in domestic stoves and small industrial plants, resulting in high concentrations of PM2.5 and PM10. For many years, the permissible concentration limits have been exceeded by benzo(a)pyrene, despite the successive decrease in its concentration (Program..., 2016). These components get into the air as a result of activity of boiler rooms of heating plants, local and industrial boiler houses, and from transportation sources.

Linear air pollutants from road traffic depend on the traffic intensity. The areas surrounding the national roads 11 and 78 and the voivodeship road 908 are most exposed to unfavorable changes in air quality.

According to the annual air quality assessment carried out by the Voivodeship Inspectorate for Environmental Protection (WIOŚ), the emission of particulate matter and gas pollutants (excluding CO_2) in the Silesian Voivodeship is continuously decreasing. The dominant gas pollutant, however, is carbon dioxide, which accounts for 98.2% of the total gas emissions (Stan..., 2020). Not only CO_2, but also methane, carbon monoxide and sulfur dioxide contribute significantly to the gas pollution. Nitrogen dioxide emissions from transport means are also important. Under conditions of high temperature and solar radiation, the ozone level limit is exceeded. Emissions of organic compounds (including aromatic hydrocarbons and solvents, formaldehyde, phenol) and heavy metals come from industrial plants of various sectors. Emission of odours (mixtures of, e.g., hydrogen sulfide, dimethyl sulfide, sulfides, etc.) occurs mainly near sewage treatment plants, and municipal and industrial waste dumps.

Surface waters and groundwater. The chemical condition of the surface waters is determined as poor (Stan..., 2020). They are polluted by discharges of sewage from treatment plants, social and household wastewater from residential buildings, and rainwater sewage. Comprehensive water and sewage management programs should reduce the pollution level in the near future.

The Stoła and Drama rivers are the major watercourses draining the map sheet area. Their waters are highly polluted. They are loaded mostly by biogenic compounds and compounds of various forms of nitrogen (Program..., 2016). The limit values of PAHs, zinc, cadmium, thallium and lead are also exceeded in the waters of the Stoła River. The Pniowiec Stream waters (a tributary of the Stoła River) are characterized by a lower-than-good potential due to oxygen conditions, salinity, acidification, and the content of biogenic compounds (Projekt...).

The groundwater is of medium and poor quality. It is polluted with nitrates, ammonia, calcium, metal oxides, trichlorethylene and tetrachlorethylene (Program..., 2016). The Quaternary aquifer system is of little utility significance. The Triassic aquifer system is unconfined or partially covered with Quaternary sediments and recharged by infiltration of precipitation directly in the outcrop areas and through permeable Quaternary sediments. The waters of the major Triassic groundwater basin (Gliwice – MGB No. 330) have been polluted with dichloroethane and tetrachloroethane by the chemical company Zakłady Chemiczne (ZCH) Tarnowskie Góry (Szadkowska, Gwóźdź, 2015; Mikołajków, Sadurski, 2017). The groundwater table of the Carboniferous aquifer system is degraded and lowered as a result of mining drainage (Razowska-Jaworek, Brodziński, 2016).

The **soils** of many areas, especially in the southeastern part of the map sheet, are polluted with heavy metals due to centuries-long mining and processing of Zn-Pb ores (Wieczorek, 2009). As their permeability is medium or good, they are capable of transferring harmful components to groundwater along with infiltrating waters (Bystrzanowski *et al.*, 2015).

At places of waste storage, the soil profile is commonly not fully developed. The soils have been repeatedly dug and dried and their natural constituents are mixed with foreign materials. The use of mining waste in the reclamation of post-industrial areas and in the road and water construction contributes to the spread of pollutants penetrating into the soil. Among the soils that are most heavily polluted with cadmium, zinc and lead are those of urban areas of Tarnowskie Góry (Lis, Pasieczna, 1995b; Pasieczna, 2003).

Landfills and post-mining areas. The mining of Zn-Pb and iron ores has left mine waste heaps (gangue rock, flotation tailings and slag from silver, lead and zinc smelting) that remained in many places in the map sheet area. They contain elements, such as As, Cd, Pb, Tl and Zn in both ore minerals and secondary mineral phases (Cabała 1996, 2009; Cabała, Teper, 2007). Over a long time, storage leads to the release of these elements in soluble compounds that pose a threat to the natural environment (Bauerek *et al.*, 2017). Clusters of large heaps and settling tanks (up to 1 km^2) are located mainly in the eastern part of the map sheet.

Particularly harmful to the environment are landfills of industrial waste from the chemical plant Zakłady Chemiczne (ZCH) Tarnowskie Góry. They contain poisons (soluble compounds of barium and strontium) or harmful substances (compounds of boron, zinc and copper). The production waste (approx. 1.2 million m^3) (1922–1995) was deposited on dumps for over 70 years in and outside the area of the plant, without any security measures (Zakłady..., 2017). The chemical compounds, when exposed to atmospheric conditions, cause the penetration of boron, barium, strontium, arsenic, copper, and zinc into soils, surface waters and groundwater, and pose a direct threat to the Major Groundwater Basin Gliwice that is a reservoir of drinking water for inhabitants of the Silesian Voivodeship. In the period 2000–2011, approximately 1 million m^3 of this hazardous waste was neutralized.

Another type of real threat to the terrain surface is the abandoned mine workings left after historical Zn-Pb ore exploitation. The mining tunnels and chambers were collapsed, the shafts were filled in, and the sites of their location are often forgotten and unmarked, making them dangerous areas for current buildings.

MATERIALS AND METHODS

The research carried out in 2017–2021 comprised the study of published and archived materials, designation of soil sampling sites on topographic maps at the scale of 1 : 10,000, soil, sediment and surface waters sampling, measurements of geographic coordinates at sampling sites, measurements of pH and electrolytic conductivity of surface waters in the field, chemical analysis of samples, development of field and laboratory databases, statistical calculations of the results of chemical analyses, construction of the topographic base map, construction of the geological map and geochemical maps, and interpretation of research results. The workflow sequence is illustrated in the attached diagram (Fig. 1).

FIELD WORKS

Soil samples were collected on a regular grid 250×250 m (16 samples/km^2). The locations of sampling sites are marked in maps showing both the built-up areas and land use (Pls. 2–3). In total, 1330 samples were taken from a depth of 0.0–0.3 m and 1290 samples from a depth of 0.8–1.0 m. In the case of a shallower depth to the bedrock, a 20-cm-thick sample was collected from just above the bedrock. Soil samples (approx. 500 g), collected with a hand auger, 60 mm in diameter, were placed in canvas bags labeled with appropriate numbers, and pre-dried on wooden pallets in a field storage facility.

Sediment and surface water samples (314 and 274 samples, respectively) were collected from rivers, streams, ditches, canals, lakes, settling tanks, and ponds. The distance between the sampling sites on watercourses was approx. 250 m. The sampling points of surface waters and sediments are presented in plates showing chemical elements content in these environmental elements, starting from plates 7 and 9, respectively. Sediment samples weighing approx. 500 g (and of the finest possible fraction) were taken from the banks of water bodies using the aluminum scoop and placed in 500 ml plastic containers, marked with appropriate numbers.

Surface water samples were collected from the same sites where sediment samples were taken. Electrolytic conductivity of water (EC) and its pH were measured in the field. For EC measurements, a conductometer with automatic temperature compensation was used, assuming the reference temperature of 25°C. Water samples were filtered in the field using 0.45 µm Milipore filters, and after filling 30 ml bottles, acidified with nitric acid. The bottles were labeled with appropriate numbers.

The sampling sites of all samples were marked on topographic maps at the scale of 1 : 10,000 and labeled with appropriate numbers.

The locations of sampling sites were determined by GPS, using a device that enables not only to measure geographic coordinates but also to record additional information (pH and EC values of water, data on the housing area, land use, and lithology of samples). The measurement of coordinates was recorded with an accuracy of ± 2–10 m. Before going into the field, the network of coordinates of the sampling sites was entered into the GPS device memory. Subsequent sampling sites were searched in the field using the satellite navigation method. For greater security, all field data were also recorded on specially prepared cards (Fig. 2).

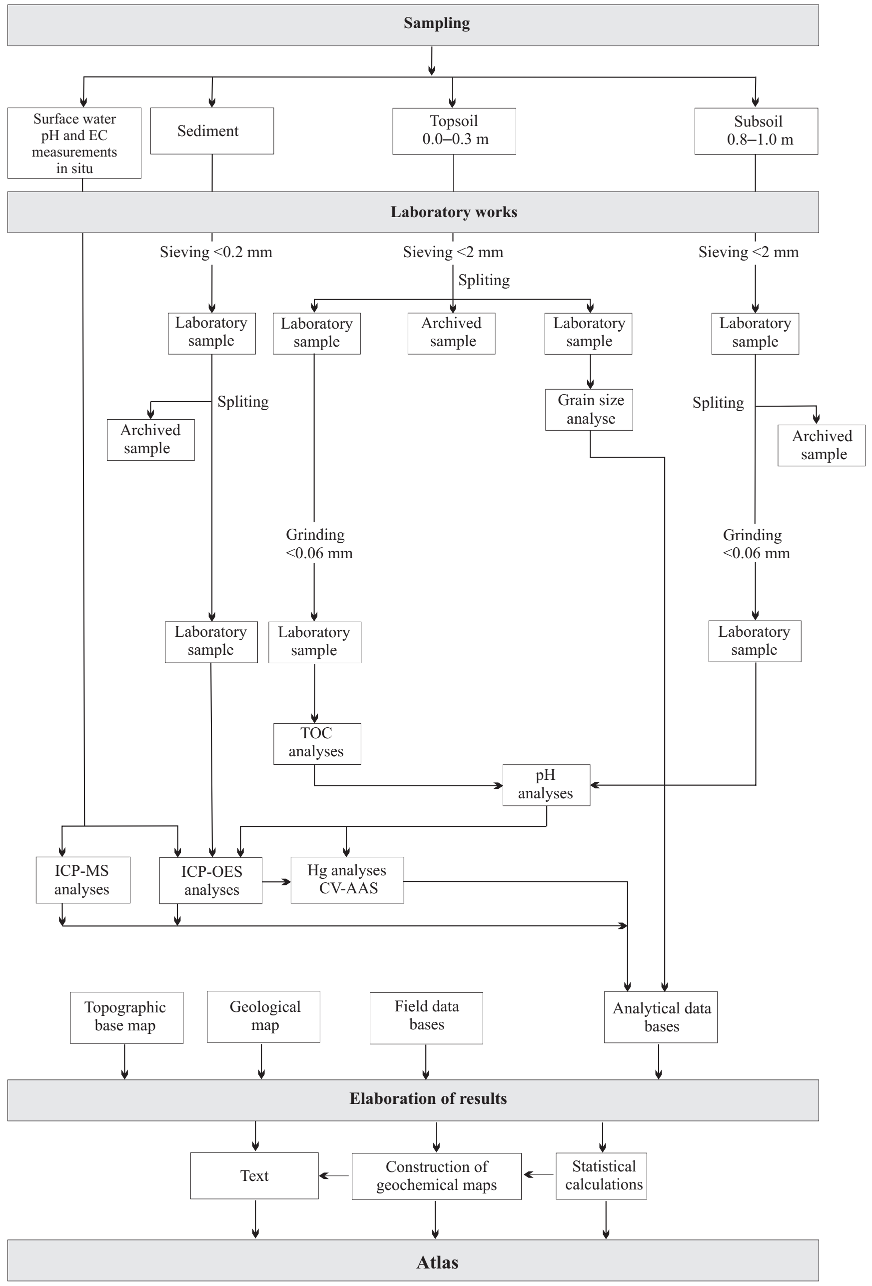
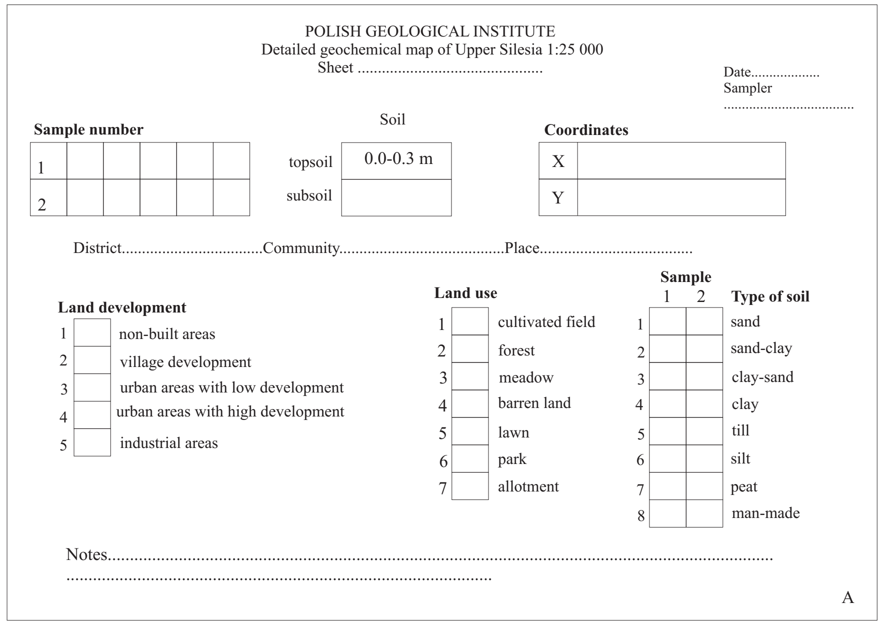


Fig. 1. Scheme of the work performed

LABORATORY WORKS

The preparation of samples for testing, determination of physicochemical parameters, and chemical analyses were performed at the Polish Geological Institute's chemical laboratory.

Sample preparation. After delivery to the laboratory, the soil samples were dried at room temperature and sieved through 2-mm-mesh nylon sieves. After sieving and quartering, each soil sample from the depth of 0.0–0.3 m was divided into three sub-samples: one for chemical analysis, the second for granulometric analysis, and the third for archival purposes, while each soil sample from the depth of 0.8–



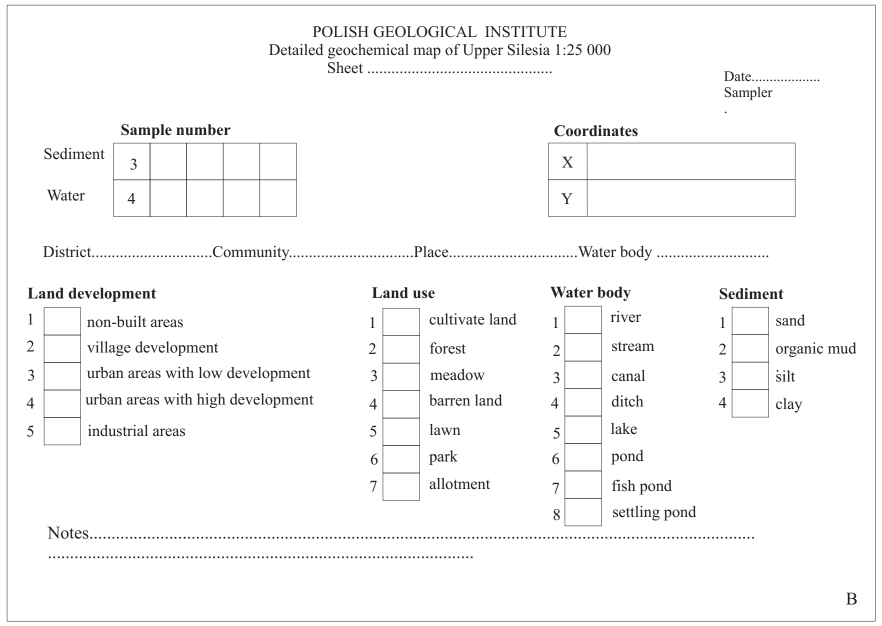


Fig. 2. Sampling cards of soils (A) as well as sediments and surface water (B)

1.0 m was divided into two sub-samples: one for chemical analysis and the other for archival purposes (Fig. 1). Soil samples designated for chemical analyses were ground in agate ball mills to the <0.06 mm fraction.

The sediment samples were dried at room temperature and then sieved through 0.2-mm-mesh nylon sieves. After quartering, the <0.2 mm fraction was divided into two sub-samples: one for chemical analysis and the other for archival purposes (Fig. 1).

The archival samples have been stored at the Polish Geological Institute in Warsaw.

Chemical analyses. Digestion of the soil and sediment samples was performed in aqua regia (1g of sample to a final volume of 50 ml) for 1 hour at 95°C in a thermostated aluminum block.

Determinations of the Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, S, Sr, Ti, V and Zn contents in soils and sediments were made using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-OES). Analyses of the Hg content in soil and sediment samples were carried out using Cold Vapor Atomic Absorption Spectrometry (CV-AAS). The soil pH was determined by the potentiometric method in the H_2O suspension, and the determination of organic carbon content (TOC) in soil by the high-temperature combustion method with IR detection.

Determination of the B, Ba, Ca, Cr, Fe, K, Mg, Mn, Na, P, SiO_2, SO_4, Sr, Ti and Zn contents in surface waters was carried out using the ICP-OES method, while ICP-MS Inductively Coupled Plasma-Mass Spectrometry was used to find out the contents of Ag, Al, As, Be, Cd, Co, Cu, Li, Mo, Ni, Pb, Sb, Se, Tl, U and V. The summary of analytical methods and detection limits of the elements is presented in Table 1.

The quality control of the determinations was carried out by analyzing duplicate samples (5% of the total number of samples), reference materials with certified content of the tested elements (2% of the total number of samples), and internal control samples confirming the correct performance of instrumental measurements (5% of the total number of samples). The purity of the reagents and vessels was controlled using "reagent blank samples" and "procedure blank samples".

The expanded uncertainty of the results (at the assumed probability level 95%, and the coverage factor k = 2) for the water, soil and sediment samples does not exceed 25%, except for the expanded uncertainty for the mercury content in the soil and sediment samples, and the organic carbon content in the soil samples, which is 30%.

Granulometric analyses of soils from the depth of 0.0–0.3 m were performed at the Polish Geological Institute's laboratory in Warsaw. The grain composition was analyzed with the sieve method in accordance with the instruction for the development of geochemical maps and the guidelines of the PN-R-04033 and BN-78/9180-11 standards.

After the organic matter had been oxidized (with hydrogen peroxide), the samples were sieved through a column of sieves of the following mesh sizes: 1 mm; 0.1 mm; 0.02 mm, and the obtained fractions of 2–1 mm, 1.0–0.1 mm and <0.02 mm were weighed.

Results of the grain-size analyses (converted into percentages) are presented on the maps of grain-size classes: 1.0–0.1 mm sand fraction, 0.1–0.02 mm silt fraction, and <0.02 mm clay fraction (Pls. 4–6).

DATABASES AND GEOCHEMICAL MAPS CONSTRUCTION

Topographic base map. The most recent 1 : 50,000 scale topographic map in the 1992 coordinate system, map sheet Bytom M-34-50-D (VMap L2 vector data), was used for the construction of the 1 : 25,000 geochemical maps. The topographic map contains the following vector information layers:

– topography;
– hydrography (subdivided into rivers, streams, ditches and stagnant water reservoirs);
– road communication network (by class);
– railway network;
– housing areas (subdivided into rural, urban and industrial housing);
– forests;
– industrial areas (industrial facilities, mine workings, heaps and settling tanks).

Geological map. To illustrate the geological structure of the study area, the 1 : 50,000 Detailed Geological Map of Poland was used, Bytom M-34-50-D sheet

Tabela 1
Table

Metody analityczne i granice oznaczalności

Analytical methods and detection limits

Pierwiastek/ związek Element/ compound	Metoda analityczna Analytical method	Jednostka Unit	Granica oznaczalności Detection limit	Metoda analityczna Analytical method	Jednostka Unit	Granica oznaczalności Detection limit
	Gleby, osady Soils, sediments			Wody powierzchniowe Surface water		
Ag	ICP-OES	mg/kg	1	ICP-MS	μg/dm³	0,05
Al	ICP-OES	%	0,01	ICP-MS	μg/dm³	0,5
As	ICP-OES	mg/kg	3	ICP-MS	μg/dm³	2
B				ICP-OES	mg/dm³	0,01
Ba	ICP-OES	mg/kg	1	ICP-OES	mg/dm³	0,001
Be				ICP-MS	μg/dm³	0,05
C_{org} (TOC)	*	%	0,02			
Ca	ICP-OES	%	0,01	ICP-OES	mg/dm³	0,1
Cd	ICP-OES	mg/kg	0,5	ICP-MS	μg/dm³	0,05
Co	ICP-OES	mg/kg	1	ICP-MS	μg/dm³	0,05
Cr	ICP-OES	mg/kg	1	ICP-OES	mg/dm³	0,003
Cu	ICP-OES	mg/kg	1	ICP-MS	μg/dm³	0,05
Fe	ICP-OES	%	0,01	ICP-OES	mg/dm³	0,01
Hg	CV-AAS	mg/kg	0,02			
K				ICP-OES	mg/dm³	0,5
Li				ICP-MS	μg/dm³	0,3
Mg	ICP-OES	%	0,01	ICP-OES	mg/dm³	0,1
Mn	ICP-OES	mg/kg	2	ICP-OES	mg/dm³	0,001
Mo				ICP-MS	μg/dm³	0,05
Na				ICP-OES	mg/dm³	0,5
Ni	ICP-OES	mg/kg	1	ICP-MS	μg/dm³	0,5
P	ICP-OES	%	0,002	ICP-OES	mg/dm³	0,05
Pb	ICP-OES	mg/kg	2	ICP-MS	μg/dm³	0,05
S	ICP-OES	%	0,003			
Sb				ICP-MS	μg/dm³	0,05
Se				ICP-MS	μg/dm³	2
SiO_2				ICP-OES	mg/dm³	0,1
SO_4				ICP-OES	mg/dm³	1
Sr	ICP-OES	mg/kg	1	ICP-OES	mg/dm³	0,003
Ti	ICP-OES	mg/kg	5	ICP-OES	mg/dm³	0,002
Tl				ICP-MS	μg/dm³	0,05
U				ICP-MS	μg/dm³	0,05
V	ICP-OES	mg/kg	1	ICP-MS	μg/dm³	1
Zn	ICP-OES	mg/kg	1	ICP-OES	mg/dm³	0,003

ICP-OES – emisyjna spektrometria atomowa ze wzbudzeniem w plazmie indukcyjnie sprzężonej
Inductively Coupled Plasma Atomic Emission Spectrometry

ICP-MS – spektrometria mas z jonizacją w plazmie indukcyjnie sprzężonej
Inductively Coupled Plasma-Mass Spectrometry

CV-AAS – absorpcyjna spektrometria atomowa z generowaniem zimnych par rtęci
Cold Vapour Atomic Absorption Spectrometry

* – wysokotemperaturowe spalanie z detekcją IR
high temperature combustion with IR detection

(Biernat, 1954; reambulation Wilanowski, Lewandowski, 2016). The vector images of the map sheet that were developed as a result of digitization were combined with the topographic base map to construct a geological map at the scale of 1 : 25,000 (Pl. 1).

Databases. Separate databases (spreadsheets) have been created for:

– soils from the depth of 0.0–0.3 m (topsoil);
– soils from the depth of 0.8–1.0 m (subsoil);
– sediments;
– surface waters.

The soil databases contain the following information: sample numbers, results of coordinate measurements at sampling sites, record of field observations (housing area type, land use, soil type, sampling site location: poviat, commune, locality), date and name of the sampling person, and results of chemical analyses.

The databases of sediments and surface waters comprise the following information: sample numbers, results of coordinate measurements at sampling sites, record of field observations (housing area type, land use, water body type, sediment type, administrative location of sampling site: poviat, commune, locality), date and name of the sampling person and the results of chemical analyses.

The sheet data are placed in separate tables (for soils, sediments and surface waters) of the professional geodatabase of the Central Geological Database (CBDG) functioning in the *Oracle* software. These tables were used to compile single-element geochemical maps in *ArcGIS 10.6*. Descriptive data (metadata), results of chemical analyses of samples, and geometric data that make up the graphic part of the study are stored in the geodatabase.

Statistical calculations. The results stored in the databases were used to extract subsets for statistical calculations according to various environmental criteria, for example, the contents of elements in soils of industrial areas, forest soils, and urban soils, and in sediments and waters of individual streams and reservoirs, as well as for the construction of geochemical maps. The calculations of statistical parameters were performed (using the *Statistica* software) for both the entire datasets and subsets for soils, sediments and surface waters. Once the content of elements was below the determination limit of the method, the content equal to half of the detection limit of the given analytical method was assumed for statistical calculations. The arithmetic mean, geometric mean, median, and minimum and maximum values were calculated. These data for individual elements and indicators are summarized in Tables 2–5 and are presented on geochemical maps (Pls. 7–62).

When interpreting the results, the calculated median values were used as a measure of the geochemical background of individual elements. The median is a statistical parameter that better characterizes the content compared to the arithmetic mean, as it is less affected by extreme values. Other statistical parameters (variance, standard deviation) are not suitable for characterizing a population of undefined distribution.

Construction of maps. The following maps were developed for the Tarnowskie Góry sheet (Pls. 2–63):

– built-up area;
– land use;
– contents of organic carbon and sand, silt and clay fractions in soils from 0.0–0.3 m depth (topsoil);
– pH in soils from 0.0–0.3 depth (topsoil) and 0.8–1.0 m depth (subsoil);
– 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 soils from the depths of 0.0 –0.3 m and 0.8–1.0 m and in sediments;
– pH and EC 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 waters;
– classification of cadmium-polluted soils from 0.0–0.3 m depth, and the indication of their proper use.

The geochemical maps were compiled using ESRI's *ArcGIS 10.6* software suitable for mapping and spatial data development. The program allows creating new maps or modifying the existing ones, analyzing and visualizing spatial data, and managing them in geodatabases.

The built-up area, land use types and the distribution of elemental contents in sediments and surface waters are presented in the form of point maps.

To demonstrate the distribution of grain classes in soils, their pH, and content of chemical elements, the isoline map construction was chosen due to its transparency and readability. The isoline geochemical maps were generated using the deterministic *Inverse Distance Weighted* (IDW) method. The method that allows obtaining a result for a given grid by averaging the values from the nearest points, and the closer points have a greater effect on the interpolated value. This effect is expressed as the reciprocal of the distance of a given point, raised to the exponent set by the performer. The advantage of the method is the determination of the distance from which points are taken into account in the interpolation process.

Maps of the distribution of grain classes, soil's pH, and elemental contents in soils have been constructed based on the set of chemical analyses for the Bytom, Piekary Śląskie, Tarnowskie Góry and Świerklaniec sheets at the scale of 1 : 25,000. One spatial analysis of the sheets was performed for each map to prevent discrepancies at their boundaries. The resulting single-element maps were combined with the topographic base within the boundaries of a given sheet.

The grain classes of soils were selected taking into account the values of calculated statistical parameters of their content in the area of the above-mentioned four sheets. The soil pH was presented according to the scale adopted in soil science (acidic, neutral and alkaline soils). The spatial distribution of selected soil elements is presented with the use of geometric progression to determine the distribution classes.

The geochemical maps of sediments of water bodies and surface waters were separately prepared for the Tarnowskie Góry sheet. They are constructed in the form of pie-chart maps, assigning the respective pie-chart diameters to individual content classes, usually arranged in a geometric progression.

When preparing the exemplary classification map of topsoils (Pl. 63), which indicates the proper way of their use due to pollution with cadmium, the results of geochemical investigations were compared to the values of permissible concentrations specified in the Regulation of the Minister of the Environment (Rozporządzenie..., 2016). The soil areas distinguished were classified into use groups I, II, III and IV.

For the purpose of publication, the geochemical maps were combined in pairs, i.e. the geochemical map of topsoils and the geochemical map of sediments are placed on one table, and the geochemical map of subsoils and the geochemical map of surface waters is presented on the adjacent one. This method of presentation allows direct comparison of geochemical images of different environments. For convenient use, the maps (with a linear scale) were printed in a slightly smaller format (A3). This procedure did not miss any detail of the map content.

RESULTS

SOILS

The most important soil-forming factor is the chemical composition of the parent rocks, which, within the map sheet limits, are lithologically diverse Triassic, Neogene and Quaternary deposits (Pl. 1). The variability of soil types is also constrained by land relief, water relations, plant cover, and human activity (Bednarek *et al.*, 2004).

In the northern part of the map sheet area, there are rusty and podzolic soils that developed on Quaternary glaciofluvial sands and loams. In the south, rendzinas are predominant, which were formed on Triassic carbonates and their weathering mantles, as well as brown and gleyed soils that developed on Quaternary sands and tills (Kościelny, Rosenbaum, 2013). Alluvial soils prevail in the river valleys covered with Holocene alluvial muds. Anthropogenic soils occur in urban, industrial and mining areas, on surfaces of artificial slopes and reclaimed heaps, and in river channels of transformed watercourses.

In the southeastern part of the map sheet, natural soils have been polluted largely with potentially toxic elements as a result of the impact of waste from the historical mining and processing of Zn-Pb ores, zinc smelting, and the activities of the Chemical Plant Tarnowskie Góry and waste storage of this plant. This part of the study area is a typical example of soil pollution from Zn-Pb ore extraction and processing (Pasieczna, 2018), like in other regions of metal ore mining and metallurgy across the world (Fuge *et al.*, 1993; Adamo *et al.*, 2002 ; Swennen *et al.*, 2002; Cappuyns *et al.*, 2005; Navarro *et al.*, 2006; Acosta *et al.*, 2011). The sources of anthropogenic soil pollution also include the deposition of dusts and gases from industrial plants, corrosion of building materials, heating of housing estates, and using plant protection products (Wong *et al.*, 2006; Albanese, Breward, 2011), as well as from transportation means (especially from large railway junctions) (Wiłkomirski *et al.*, 2011; Stojič *et al.*, 2017). The source of soil pollution in the river valleys is periodic floods from rivers transporting heavily polluted waters and sediments to floodplain terraces.

Grain-size composition. Grain-size composition determines the fragmentation of the mineral part of the soil phase and is expressed by the size of particles and the percentage of each grain-size fraction (Bednarek *et al.*, 2004). Under natural conditions, the soil grain-size composition changes very little and is one of the most important features affecting physical, chemical and biological properties of soils (Mocek *et al.*, 2000; Ryżak *et al.*, 2009).

In the study, the subdivision of soil particles into grain-size groups has been adopted from the standard BN-78/9180-11, valid until 2008, because it is a continuation of the serial project carried out permanently for several years now in accordance with the instructions for the geochemical map at the scale of 1 : 25,000. The results of grain-size analyses are presented for the following grain groups: 1.0–0.1 mm sand fraction, 0.1–0.02 mm silt fraction, <0.02 mm clay fraction (Pls. 4–6). Changing the ranges of grain-size groups in accordance with the current guidelines of the Polish Soil Science Society (Klasyfikacja..., 2008) would make it impossible to compare the grain-size composition with the data from the previously developed sheets.

The grain-size composition of the studied soils is clearly related to the lithology of the parent material. In the map sheet area, soils rich in the sand fraction predominate. In its northern and central parts, covered with glaciofluvial sands and gravels, the content of this fraction exceeds 60% (Pl. 4), whereas in other regions, it is commonly 40–60%. The most sandy soils least abundant in the clay fraction (often <10%) cover the right-hand side of the Stoła River drainage basin, covered with forests.

In turn, soils of the western and southern parts of the study area, which developed on Quaternary tills and Triassic carbonates and are used mostly as arable land, are characterized by the content of the silt and clay fractions (over 20%) (Pls. 5 and 6), positively affecting their properties. These fractions consist mainly of clay minerals and secondary oxide minerals, which determine the ability to retain both plant nutrients and toxic elements.

Tabela 2
Table

Parametry statystyczne zawartości pierwiastków chemicznych i odczynu gleb (0,0–0,3 m)

Statistical parameters of chemical elements contents and acidity of topsoils (0.0–0.3 m)

Gleby Soils	Parametry Parameters	Ag mg/kg	Al %	As mg/kg	Ba mg/kg	$C_{org.}$ %	Ca %	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Hg mg/kg	Mg %	Mn mg/kg	Ni mg/kg	P %	Pb mg/kg	S %	Sr mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg	pH
Granica wykrywalności Detection limit		1	0,01	3	1	0,02	0,01	0,5	1	1	1	0,01	0,02	0,01	2	1	0,002	2	0,003	1	5	1	1	
	a	<1	0,03	<3	14	0,15	<0,01	<0,5	<1	<1	1	0,02	<0,02	<0,01	<2	<1	<0,002	5	<0,003	<1	<5	<1	5	3,37
Gleby ogółem	b	18	2,41	997	47 151	48,60	18,12	66,4	36	274	2266	15,26	1,94	7,03	12 928	93	0,612	15 500	4,485	3758	706	89	37 005	9,53
Soils as a whole	c	<1	0,46	10	319	3,73	0,39	2,6	3	9	25	0,89	0,08	0,13	436	7	0,043	291	0,038	26	67	12	374	6,19
n = 1330	d	<1	0,39	6	162	2,20	0,11	1,3	2	7	11	0,59	0,05	0,05	157	4	0,033	136	0,025	11	53	9	128	6,02
	e	<1	0,44	5	135	1,82	0,12	1,2	2	7	9	0,63	0,05	0,06	298	5	0,038	116	0,022	9	54	11	110	6,53
	a	<1	0,03	<3	14	0,15	<0,01	<0,5	<1	<1	1	0,02	<0,02	<0,01	<2	<1	<0,002	5	<0,003	<1	<5	<1	5	3,37
Tereny bez zabudowy	b	10	2,34	997	21 733	48,60	18,12	48,4	19	274	1977	15,26	1,94	7,03	10 423	93	0,612	15 500	4,485	3758	527	88	8403	9,13
Non-built-up areas	c	<1	0,44	9	270	4,09	0,24	2,0	2	8	20	0,75	0,07	0,08	334	6	0,040	221	0,038	22	55	11	232	5,80
n = 964	d	<1	0,36	5	141	2,23	0,07	1,1	2	6	9	0,50	0,05	0,04	107	3	0,029	111	0,023	8	45	9	87	5,64
	e	<1	0,42	5	111	1,72	0,09	1,0	2	6	8	0,56	0,04	0,05	216	4	0,035	97	0,020	8	46	10	87	6,03
	a	<1	0,09	<3	42	0,54	0,02	<0,5	<1	2	3	0,12	<0,02	0,01	15	<1	0,011	11	0,006	3	<5	3	28	4,55
Tereny z zabudową wiejską	b	18	1,34	720	833	20,96	3,43	66,4	15	54	88	8,93	0,27	2,23	4299	57	0,151	10 080	0,201	256	511	84	37 005	9,03
Village areas	c	<1	0,47	14	228	2,57	0,40	3,1	3	9	16	0,91	0,05	0,14	433	7	0,057	385	0,032	24	77	12	742	6,83
n = 90	d	<1	0,42	5	171	2,00	0,20	1,6	2	7	12	0,66	0,04	0,08	267	5	0,049	162	0,025	15	53	10	201	6,78
	e	<1	0,41	5	159	1,85	0,18	1,4	3	7	11	0,66	0,04	0,07	354	5	0,049	121	0,024	12	55	10	189	6,84
	a	<1	0,15	<3	39	0,24	0,02	<0,5	<1	2	4	0,24	<0,02	0,01	31	1	0,012	19	0,005	4	6	2	48	4,48
Tereny z zabudową miejską	b	4	2,41	189	2046	21,78	9,76	63,0	36	139	716	13,23	1,49	4,77	12 928	85	0,200	12 480	0,192	220	706	89	6993	9,53
Urban areas	c	<1	0,53	13	346	2,61	0,82	4,4	4	13	32	1,36	0,10	0,25	817	10	0,053	506	0,035	32	103	15	746	7,35
n = 223	d	<1	0,49	9	248	2,07	0,39	2,7	3	10	19	1,04	0,06	0,13	528	8	0,045	254	0,029	22	89	13	428	7,31
	e	<1	0,50	7	230	2,02	0,40	2,4	3	9	19	0,97	0,06	0,11	493	8	0,046	231	0,028	22	82	13	395	7,47
	a	<1	0,03	<3	49	0,15	0,02	<0,5	<1	<1	3	0,05	<0,02	<0,01	16	<1	0,005	23	0,005	5	16	<1	39	4,67
Tereny przemysłowe	b	4	1,02	138	47 151	19,24	12,24	62,4	11	97	2266	7,52	0,60	5,11	6166	33	0,176	3779	0,202	2018	332	35	6813	9,18
Industrial areas	c	<1	0,52	13	1255	3,79	1,35	4,9	4	15	95	1,36	0,10	0,45	693	11	0,043	493	0,043	78	126	14	752	7,36
n = 53	d	<1	0,47	8	308	2,52	0,49	2,4	3	11	30	1,04	0,06	0,16	453	9	0,035	272	0,031	30	103	12	384	7,30
	e	<1	0,48	8	272	2,36	0,56	2,8	3	11	23	1,09	0,07	0,16	424	10	0,034	243	0,029	32	92	13	386	7,58
	a	<1	0,17	<3	26	0,17	0,02	<0,5	1	3	3	0,22	<0,02	0,02	68	1	0,011	11	0,006	2	12	4	29	5,00
Pola uprawne	b	2	2,27	58	833	6,88	3,95	33,4	18	49	67	6,80	0,34	1,78	5769	48	0,200	2363	0,076	231	259	36	7648	8,20
Cultivated fields	c	<1	0,53	6	111	1,29	0,26	1,7	3	9	10	0,86	0,04	0,11	482	7	0,052	133	0,018	10	66	13	220	6,91
n = 399	d	<1	0,50	5	95	1,20	0,16	1,2	3	8	8	0,74	0,04	0,08	389	6	0,049	78	0,017	8	59	13	130	6,89
	e	<1	0,49	5	86	1,17	0,15	1,1	3	8	8	0,68	0,04	0,08	398	5	0,048	63	0,016	8	60	13	108	6,97
	a	<1	0,03	<3	14	0,15	<0,01	<0,5	<1	<1	1	0,02	<0,02	<0,01	1	<1	<0,002	5	<0,003	<1	<5	<1	5	3,37
Lasy	b	5	1,64	228	47 151	48,60	18,12	30,4	14	81	354	13,38	1,85	7,03	3951	36	0,483	4128	0,753	2018	527	59	5708	9,13
Forests	c	<1	0,34	6	487	6,30	0,11	1,5	1	5	14	0,47	0,08	0,04	102	3	0,023	202	0,043	18	43	8	104	4,61
n = 442	d	<1	0,25	4	189	3,75	0,03	0,8	<1	4	8	0,30	0,05	0,02	25	2	0,017	127	0,029	7	35	6	46	4,54
	e	<1	0,28	5	192	3,32	0,02	0,8	<1	4	7	0,30	0,05	0,01	16	2	0,016	125	0,027	7	36	6	38	4,44
	a	<1	0,03	<3	29	0,79	0,01	<0,5	<1	<1	1	0,05	<0,02	<0,01	10	<1	0,005	23	0,009	2	<5	<1	18	4,20
Łąki	b	4	2,34	155	1441	35,15	2,59	16,4	10	32	1977	2,78	1,50	0,63	2187	26	0,391	7187	0,355	163	118	65	2148	7,76
Meadows	c	<1	0,50	10	185	3,91	0,25	2,3	2	8	29	0,76	0,08	0,07	324	5	0,056	322	0,039	17	42	12	243	6,30
n = 103	d	<1	0,40	6	148	2,29	0,14	1,4	2	6	9	0,58	0,05	0,05	216	4	0,045	151	0,026	12	35	9	142	6,26
	e	<1	0,41	5	145	2,00	0,14	1,3	2	6	8	0,58	0,04	0,05	277	4	0,044	122	0,023	11	37	10	121	6,33
	a	<1	0,06	<3	17	0,15	0,01	<0,5	<1	2	3	0,13	<0,02	<0,01	10	<1	0,009	14	0,004	3	6	3	22	4,30
Nieużytki, ugory	b	10	2,41	997	3401	41,47	16,42	63,0	36	274	2266	13,23	1,94	5,11	12 928	85	0,612	15 500	4,485	3758	414	78	8403	8,67
Barren lands	c	<1	0,53	23	376	3,68	0,84	5,5	4	13	75	1,49	0,11	0,23	810	11	0,056	631	0,066	70	79	15	853	6,90
n = 178	d	<1	0,48	9	227	2,10	0,26	2,4	3	9	19	0,98	0,06	0,10	413	7	0,043	238	0,029	20	65	12	338	6,84
	e	<1	0,48	7	193	1,70	0,21	2,0	3	9	12	0,84	0,06	0,08	400	7	0,042	214	0,026	16	68	12	299	6,98
	a	<1	0,24	<3	75	0,93	0,06	0,8	<1	4	5	0,47	0,02	0,03	200	3	0,022	55	0,012	5	32	4	93	5,78
Ogródki działkowe	b	1	0,98	67	4557	7,00	2,38	16,3	8	74	92	3,36	0,22	1,04	3521	24	0,171	1177	0,177	368	208	88	3775	8,91
Allotments	c	<1	0,53	12	537	2,57	0,67	3,8	3	13	26	1,30	0,07	0,20	727	10	0,075	384	0,037	52	99	18	688	7,04
n = 17	d	<1	0,49	8	275	2,14	0,32	2,6	3	10	18	1,06	0,06	0,11	558	8	0,063	265	0,027	24	80	13	386	7,00
	e	<1	0,46	7	246	1,87	0,22	2,7	3	10	27	1,03	0,04	0,07	516	9	0,058	265	0,024	18	73	12	440	7,02

Tabela 2 cd.
Table 2 cont.

Gleby Soils	Parametry Parameters	Ag mg/kg	Al %	As mg/kg	Ba mg/kg	$C_{org.}$ %	Ca %	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Hg mg/kg	Mg %	Mn mg/kg	Ni mg/kg	P %	Pb mg/kg	S %	Sr mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg	pH
	a	<1	0,17	<3	28	0,89	<0,01	<0,5	<1	2	2	0,08	<0,02	0,01	7	<1	0,003	35	0,007	2	47	3	8	5,21
Parki	b	5	1,10	140	628	5,25	2,38	27,2	17	50	58	15,26	0,33	0,46	10 423	93	0,079	3675	0,052	111	284	54	4721	8,04
Parks	c	<1	0,54	17	161	1,88	0,36	3,6	4	11	15	1,84	0,08	0,11	1120	12	0,026	466	0,019	16	105	14	603	6,27
n = 19	d	<1	0,48	8	101	1,61	0,07	1,1	3	8	9	0,84	0,04	0,07	281	6	0,018	155	0,016	8	93	11	129	6,21
	e	<1	0,52	6	86	1,45	0,03	0,8	3	8	7	0,69	0,03	0,07	319	5	0,016	90	0,015	5	82	10	74	5,92
	a	<1	0,24	<3	39	0,24	0,07	<0,5	<1	4	4	0,29	<0,02	0,04	103	3	0,012	22	0,005	5	28	3	59	6,00
Trawniki	b	18	1,84	720	3185	21,78	8,33	66,4	15	139	716	8,93	1,49	4,77	5594	57	0,197	10 080	0,201	256	706	89	37 005	9,53
Lawns	c	<1	0,54	16	392	3,03	1,04	4,4	4	14	35	1,36	0,11	0,31	761	11	0,052	484	0,041	42	127	16	949	7,69
n = 172	d	<1	0,51	9	279	2,42	0,62	3,0	3	12	24	1,13	0,07	0,18	572	9	0,046	278	0,034	30	108	14	534	7,67
	e	<1	0,51	8	267	2,35	0,61	2,9	3	11	23	1,13	0,07	0,15	525	9	0,046	267	0,033	32	103	13	547	7,72
	a	<1	0,03	<3	14	0,15	<0,01	<0,5	<1	<1	1	0,02	<0,02	<0,01	1	<1	<0,002	5	<0,003	<1	<5	<1	5	3,37
Gleby piaszczyste	b	4	1,56	247	3401	39,82	16,42	42,6	27	97	1165	13,38	0,93	1,25	10 264	85	0,483	7187	0,189	1819	284	68	7648	9,18
Sandy soils	c	<1	0,39	7	229	2,65	0,17	1,6	2	7	14	0,65	0,05	0,06	304	5	0,037	185	0,025	14	55	9	196	5,90
n = 935	d	<1	0,33	5	139	1,93	0,06	1,0	1	5	8	0,46	0,04	0,03	108	3	0,028	108	0,021	8	47	8	86	5,76
	e	<1	0,39	5	117	1,66	0,08	1,0	2	6	7	0,52	0,04	0,05	218	4	0,034	99	0,019	8	48	9	83	6,24
	a	<1	0,20	<3	34	0,57	<0,01	<0,5	<1	2	3	0,10	<0,02	<0,01	6	<1	0,008	19	0,008	2	<5	3	13	4,03
Gleby gliniaste	b	5	2,27	140	2195	6,67	18,12	30,3	19	50	31	15,26	0,34	7,03	10 423	93	0,105	15 500	0,064	79	156	54	5708	8,27
Clay soils	c	<1	0,70	10	142	1,81	0,54	2,3	5	12	11	1,35	0,06	0,26	718	11	0,046	297	0,023	12	55	17	341	6,55
n = 134	d	<1	0,65	7	111	1,60	0,17	1,3	4	11	10	1,04	0,05	0,12	381	8	0,040	101	0,021	9	49	15	142	6,45
	e	<1	0,60	7	105	1,47	0,18	1,3	4	10	11	0,93	0,05	0,09	500	8	0,047	83	0,021	9	51	15	126	6,80
	a	<1	0,10	<3	59	1,80	<0,01	<0,5	<1	2	6	0,14	<0,02	<0,01	7	1	0,018	92	0,029	8	<5	3	31	3,43
Gleby torfiaste	b	10	2,41	227	1412	48,60	2,63	48,4	7	274	1977	4,89	1,94	0,37	583	55	0,612	4128	0,753	826	290	78	8403	6,82
Peaty soils	c	<1	0,64	22	573	25,19	0,39	6,4	2	15	113	0,90	0,28	0,05	127	7	0,096	667	0,163	46	43	19	458	4,53
n = 57	d	<1	0,50	13	485	20,42	0,16	4,6	1	9	33	0,67	0,20	0,03	58	5	0,066	496	0,136	27	28	14	224	4,43
	e	<1	0,47	10	524	24,18	0,12	4,4	1	8	27	0,65	0,21	0,02	40	5	0,059	498	0,141	23	36	12	203	4,02
	a	<1	0,24	<3	17	0,16	0,08	<0,5	<1	4	4	0,35	<0,02	0,04	103	4	0,009	22	0,005	5	30	5	59	6,00
Gleby antropogeniczne	b	18	1,87	997	47 151	41,47	14,37	66,4	36	139	2266	11,11	1,85	5,11	12 928	62	0,197	12 480	4,485	3758	706	89	37 005	9,53
Man-made soils	c	<1	0,58	25	780	3,94	1,34	6,1	4	17	61	1,69	0,12	0,39	941	13	0,055	666	0,069	85	137	18	1184	7,73
n = 204	d	<1	0,54	11	308	2,67	0,78	3,5	4	13	30	1,34	0,07	0,21	647	11	0,047	322	0,037	37	116	15	636	7,71
	e	<1	0,53	10	267	2,56	0,83	3,3	4	12	27	1,25	0,08	0,19	558	11	0,048	295	0,037	35	106	15	606	7,75
Tło geochemiczne; geochemical background																								
Gleby Europy [1]; Soils of Europe n = 837	e	0,27	5,82	6	65	1,73	0,92	0,15	7	22	12	1,96	0,04	0,46	524	14	0,055	15	0,023	89	3420	33	48	7,7
Gleby Polski [2]; Soils of Poland n = 10 840	e	<1		<5	32		0,18	<0,5	2	4	5	0,51	<0,05	0,06	217	4	0,034	13	0,012	8	26	7	35	6,1
Gleby regionu śląsko-krakowskiego [3] Soils of Cracow-Silesia Region n = 1564	e	<1		<5	54		0,22	1,3	3	5	7	0,63	0,08	0,07	257	5	0,030	44	0,015	10	28	9	104	6,7
Dopuszczalne zawartości pierwiastków powodujących ryzyko [4]; permissible levels of elements causing the risk																								
I grupa; group I				25	400			2	50	200	200		5			150		200					500	
II grupa; group II				10–50	200–600			2–5	20–50	150–500	100–300		2–5			100–300		100–500					300–1000	
III grupa; group III				50	1000			10	100	500	300		10			300		500					1000	
IV grupa; group IV				100	1500			15	200	1000	600		30			500		600					2000	

a – minimum; minimum b – maksimum; maximum c – średnia arytmetyczna; arithmetic mean d – średnia geometryczna; geometric mean e – mediana; median n – liczba próbek; number of samples [1] Salminen red., 2005; [2] Lis, Pasieczna, 1995a; [3] Lis, Pasieczna, 1995b; [4] Rozporządzenie Ministra Środowiska, 2016

Tabela 3
Table

Parametry statystyczne zawartości pierwiastków chemicznych i odczynu gleb (0,8–1,0 m)

Statistical parameters of chemical elements contents and acidity of subsoils (0.8–1.0 m)

Gleby Soils	Parametry Parameters	Ag mg/kg	Al %	As mg/kg	Ba mg/kg	Ca %	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Hg mg/kg	Mg %	Mn mg/kg	Ni mg/kg	P %	Pb mg/kg	S %	Sr mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg	pH
Granica wykrywalności Detection limit		1	0,01	3	1	0,01	0,5	1	1	1	0,01	0,02	0,01	2	1	0,002	2	0,003	1	5	1	1	
	a	<1	0,05	<3	8	<0,01	<0,5	<1	<1	<1	0,01	<0,02	<0,01	2	<1	<0,002	<2	<0,003	<1	6	<1	3	3,45
Gleby ogółem	b	26	3,97	219	63 112	24,70	152,2	57	169	1725	9,34	1,90	8,49	7322	243	0,953	52 190	1,006	2915	814	69	24 201	9,26
Soils as a whole	c	<1	0,46	5	131	0,47	1,5	3	8	12	0,79	0,03	0,18	290	9	0,020	156	0,014	14	75	10	225	6,74
n = 1290	d	<1	0,38	3	37	0,05	<0,5	2	5	4	0,42	<0,02	0,05	74	4	0,009	13	0,005	5	64	7	32	6,66
	e	<1	0,40	<3	29	0,04	<0,5	2	5	4	0,46	<0,02	0,05	73	4	0,008	9	0,004	4	64	8	22	6,85
	a	<1	0,05	<3	8	<0,01	<0,5	<1	<1	<1	0,01	<0,02	<0,01	2	<1	<0,002	<2	<0,003	<1	6	<1	3	3,45
Tereny bez zabudowy	b	26	3,97	219	2462	24,70	152,2	57	108	1053	9,34	0,89	8,49	7322	243	0,433	52 190	1,006	498	814	69	24 201	9,26
Non-built-up areas	c	<1	0,44	5	54	0,43	1,1	3	8	9	0,74	0,02	0,18	234	9	0,017	128	0,013	9	67	9	156	6,51
n = 946	d	<1	0,36	<3	30	0,03	<0,5	1	5	4	0,36	<0,02	0,04	54	3	0,008	8	0,004	4	57	6	22	6,44
	e	<1	0,36	<3	26	0,03	<0,5	1	5	3	0,37	<0,02	0,04	51	3	0,007	7	0,004	3	58	7	17	6,60
	a	<1	0,14	<3	16	0,01	<0,5	<1	1	<1	0,06	<0,02	<0,01	6	<1	<0,002	3	<0,003	2	25	1	6	5,01
Tereny z zabudową wiejską	b	1	1,28	33	371	1,67	12,6	11	24	116	2,27	0,21	0,29	2209	20	0,217	1202	0,336	118	259	26	2350	8,35
Village areas	c	<1	0,48	3	53	0,13	0,7	3	7	7	0,63	0,02	0,07	199	6	0,019	72	0,010	8	89	9	120	6,88
n = 89	d	<1	0,43	<3	40	0,06	<0,5	2	6	5	0,46	<0,02	0,05	97	4	0,012	20	0,005	5	79	8	41	6,84
	e	<1	0,44	<3	35	0,05	<0,5	2	6	4	0,54	<0,02	0,06	105	5	0,010	13	0,004	4	83	9	26	6,88
	a	<1	0,09	<3	13	<0,01	<0,5	<1	<1	1	0,06	<0,02	<0,01	6	<1	<0,002	<2	<0,003	1	34	2	5	4,83
Tereny z zabudową miejską	b	9	2,11	176	3334	10,99	53,2	17	169	1725	9,32	1,90	4,95	4686	104	0,953	5862	0,146	241	360	60	9278	8,88
Urban areas	c	<1	0,50	9	167	0,71	2,4	3	9	21	1,01	0,07	0,21	518	8	0,030	266	0,017	22	99	11	480	7,53
n = 209	d	<1	0,45	4	70	0,15	0,8	2	7	7	0,67	0,02	0,08	204	5	0,017	53	0,007	9	88	9	110	7,49
	e	<1	0,46	3	54	0,10	<0,5	2	6	6	0,63	<0,02	0,07	197	5	0,015	42	0,006	7	85	9	79	7,59
	a	<1	0,17	<3	20	<0,01	<0,5	<1	2	1	0,10	<0,02	0,02	10	1	<0,002	3	<0,003	2	39	3	8	5,70
Tereny przemysłowe	b	6	1,27	112	63 112	5,17	100,1	10	43	581	7,46	0,84	2,24	5781	48	0,141	4328	0,133	2915	273	37	10 421	8,82
Industrial areas	c	<1	0,49	12	1705	0,87	4,8	3	11	36	1,15	0,08	0,23	584	10	0,025	381	0,023	97	104	12	691	7,59
n = 46	d	<1	0,45	5	127	0,23	1,1	2	8	13	0,74	0,03	0,10	253	7	0,017	93	0,011	15	96	10	165	7,55
	e	<1	0,46	5	92	0,26	1,0	3	7	13	0,73	0,02	0,08	255	7	0,016	96	0,010	10	95	10	181	7,63
	a	<1	0,12	<3	8	<0,01	<0,5	<1	2	1	0,07	<0,02	0,02	7	<1	<0,002	<2	<0,003	1	6	2	5	4,89
Pola uprawne	b	3	2,37	73	1054	18,00	152,2	57	108	102	9,34	0,20	8,49	7322	243	0,364	2426	0,095	170	268	69	24 201	9,26
Cultivated fields	c	<1	0,56	5	42	0,62	1,0	5	11	10	1,08	0,02	0,30	349	16	0,023	40	0,006	9	76	13	177	7,03
n = 394	d	<1	0,48	<3	31	0,09	<0,5	3	8	6	0,69	<0,02	0,08	141	7	0,013	10	0,004	5	66	10	31	6,98
	e	<1	0,49	<3	28	0,06	<0,5	3	7	5	0,68	<0,02	0,07	123	6	0,011	9	0,003	4	70	10	23	7,11
	a	<1	0,06	<3	8	<0,01	<0,5	<1	<1	<1	0,02	<0,02	<0,01	2	<1	<0,002	<2	<0,003	<1	8	<1	3	3,45
Lasy	b	26	3,97	219	7422	18,40	121,5	31	43	57	7,83	0,32	6,84	3458	94	0,433	52 190	0,702	385	410	54	11 123	8,63
Forests	c	<1	0,32	<3	53	0,13	0,7	1	4	4	0,35	<0,02	0,07	72	3	0,009	140	0,012	5	56	5	60	5,99
n = 439	d	<1	0,26	<3	25	0,01	<0,5	<1	3	2	0,18	<0,02	0,02	18	2	0,005	5	0,004	2	49	4	12	5,93
	e	<1	0,23	<3	23	<0,01	<0,5	<1	3	2	0,15	<0,02	0,02	13	2	0,004	4	0,004	2	49	3	10	6,10
	a	<1	0,05	<3	9	<0,01	<0,5	<1	<1	<1	0,01	<0,02	<0,01	4	<1	<0,002	<2	<0,003	1	9	1	3	5,01
Łąki	b	5	1,38	128	1487	16,08	52,98	32	32	119	7,52	0,24	5,56	3655	116	0,227	9267	0,592	71	233	54	4975	8,32
Meadows	c	<1	0,45	5	55	0,40	0,87	3	7	7	0,72	0,02	0,16	214	7	0,019	110	0,024	8	70	10	89	6,61
n = 100	d	<1	0,37	<3	32	0,05	<0,5	2	5	3	0,38	<0,02	0,04	71	3	0,010	10	0,004	4	59	7	24	6,57
	e	<1	0,40	<3	27	0,04	<0,5	1	5	3	0,41	<0,02	0,05	73	3	0,009	9	0,004	4	59	7	21	6,76
	a	<1	0,09	<3	10	<0,01	<0,5	<1	<1	<1	0,03	<0,02	<0,01	4	<1	<0,002	<2	<0,003	2	18	1	5	4,32
Nieużytki, ugory	b	9	2,11	163	1939	24,70	100,1	18	169	1725	7,46	1,90	3,86	5781	104	0,953	10 350	1,006	498	814	60	10 421	8,72
Barren lands	c	<1	0,51	10	137	0,65	3,5	3	10	34	0,98	0,06	0,17	423	9	0,030	310	0,027	21	91	11	513	7,07
n = 162	d	<1	0,44	4	60	0,11	0,6	2	7	7	0,60	<0,02	0,07	141	5	0,013	37	0,007	8	78	9	81	7,02
	e	<1	0,46	3	42	0,07	<0,5	2	7	6	0,59	<0,02	0,06	150	5	0,012	23	0,005	5	76	9	43	7,20

Tabela 3 cd.
Table 3 cont.

Gleby Soils	Parametry Parameters	Ag mg/kg	Al %	As mg/kg	Ba mg/kg	Ca %	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Hg mg/kg	Mg %	Mn mg/kg	Ni mg/kg	P %	Pb mg/kg	S %	Sr mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg	pH
	a	<1	0,22	<3	18	0,02	<0,5	<1	3	1	0,20	<0,02	0,03	17	2	0,003	3	<0,003	2	42	4	11	5,36
Ogródki działkowe	b	3	1,00	100	1847	4,82	13,5	11	25	148	6,28	0,21	0,23	2625	38	0,217	4287	0,077	156	232	25	5875	8,07
Allotments	c	<1	0,58	10	183	0,59	2,1	3	10	17	1,26	0,03	0,10	446	11	0,033	385	0,014	25	108	13	498	7,10
n = 17	d	<1	0,54	4	64	0,14	0,6	2	8	8	0,85	0,02	0,08	173	7	0,018	44	0,007	9	94	11	82	7,05
	e	<1	0,56	3	50	0,11	<0,5	3	8	7	0,79	<0,02	0,08	185	5	0,014	47	0,005	7	89	11	63	7,38
	a	<1	0,23	<3	18	<0,01	<0,5	<1	3	<1	0,10	<0,02	0,02	14	1	0,003	3	<0,003	2	27	2	8	4,96
Parki	b	1	1,27	30	416	2,81	14,6	22	32	38	4,04	0,36	0,28	3145	56	0,065	1238	0,064	83	205	29	1828	8,36
Parks	c	<1	0,58	7	70	0,40	1,7	5	11	10	1,17	0,04	0,09	535	11	0,019	177	0,011	13	98	12	260	6,82
n = 19	d	<1	0,50	4	43	0,07	<0,5	3	8	5	0,73	<0,02	0,07	181	6	0,012	29	0,005	6	91	9	67	6,75
	e	<1	0,43	<3	33	0,07	<0,5	2	6	4	0,60	<0,02	0,07	149	5	0,009	28	0,005	4	97	8	47	6,98
	a	<1	0,09	<3	18	0,02	<0,5	<1	<1	2	0,07	<0,02	<0,01	11	<1	0,003	4	<0,003	2	34	2	9	5,35
Trawniki	b	7	1,37	176	63 112	10,26	44,1	9	51	308	5,48	0,98	4,95	4686	28	0,133	5862	0,336	2915	360	41	7371	8,88
Lawns	c	<1	0,52	10	609	0,87	2,9	3	9	17	1,08	0,08	0,25	616	8	0,029	331	0,022	45	108	12	558	7,78
n = 159	d	<1	0,47	5	100	0,26	1,0	2	7	9	0,78	0,03	0,10	300	6	0,021	97	0,010	14	96	10	179	7,76
	e	<1	0,48	5	79	0,20	1,0	3	7	9	0,73	0,03	0,09	279	6	0,022	104	0,010	10	90	10	179	7,83
	a	<1	0,05	<3	8	<0,01	<0,5	<1	<1	<1	0,01	<0,02	<0,01	2	<1	<0,002	<2	<0,003	<1	13	<1	3	3,70
Gleby piaszczyste	b	7	1,10	97	1924	3,39	43,3	32	56	109	9,32	0,57	1,95	4395	48	0,141	10 350	0,107	103	268	45	4816	8,82
Sandy soils	c	<1	0,34	<3	40	0,06	<0,5	2	5	4	0,42	<0,02	0,04	113	4	0,009	38	0,005	4	67	6	50	6,61
n = 909	d	<1	0,30	<3	26	0,02	<0,5	1	4	3	0,26	<0,02	0,03	39	2	0,006	7	0,003	3	60	5	17	6,55
	e	<1	0,31	<3	24	0,02	<0,5	1	4	2	0,29	<0,02	0,03	39	3	0,006	6	0,004	3	60	5	15	6,72
	a	<1	0,30	<3	16	<0,01	<0,5	<1	5	2	0,24	<0,02	0,04	15	2	0,003	3	<0,003	2	6	5	11	4,40
Gleby gliniaste	b	5	2,37	128	1487	24,70	152,2	57	108	119	9,34	0,20	8,49	7322	243	0,364	9267	0,122	498	410	69	24 201	9,26
Clay soils	c	<1	0,80	9	72	1,46	1,9	8	18	16	1,80	0,03	0,63	621	26	0,039	138	0,012	18	81	20	366	6,77
n = 246	d	<1	0,74	5	51	0,22	<0,5	5	15	11	1,39	0,02	0,18	277	14	0,022	26	0,007	10	64	18	70	6,67
	e	<1	0,73	4	46	0,14	<0,5	5	13	10	1,24	0,02	0,12	300	11	0,021	15	0,006	7	69	17	38	6,94
	a	<1	0,09	<3	13	<0,01	<0,5	<1	1	2	0,03	<0,02	<0,01	5	1	<0,002	2	0,004	1	12	2	7	3,45
Gleby torfiaste	b	9	3,97	163	1939	2,45	97,7	18	169	1725	2,95	1,90	0,23	1087	39	0,953	2686	1,006	241	93	54	10 148	7,23
Peaty soils	c	1	0,76	23	240	0,99	10,6	2	19	161	0,57	0,28	0,08	152	9	0,132	383	0,291	53	36	18	1175	5,49
n = 21	d	<1	0,45	7	122	0,43	2,0	1	8	19	0,31	0,11	0,05	64	5	0,049	63	0,175	29	30	12	135	5,39
	e	<1	0,55	5	121	0,68	1,3	<1	10	12	0,32	0,12	0,07	72	5	0,047	50	0,210	47	25	16	89	5,69
	a	<1	0,23	<3	29	0,03	<0,5	<1	3	2	0,17	<0,02	0,02	32	2	0,004	17	<0,003	3	36	3	29	5,93
Gleby antropogeniczne	b	26	1,37	219	63 112	10,26	121,5	11	51	581	7,83	0,98	3,61	5781	39	0,217	52 190	0,336	2915	814	41	11 123	8,88
Man-made soils	c	1	0,60	19	961	1,53	6,8	4	12	34	1,65	0,12	0,35	1019	12	0,043	1090	0,041	76	137	15	1139	7,96
n = 114	d	<1	0,57	11	225	0,79	2,7	3	11	20	1,29	0,06	0,19	645	10	0,035	309	0,026	34	119	14	522	7,94
	e	<1	0,57	9	200	0,85	2,9	4	10	20	1,23	0,07	0,17	625	9	0,038	333	0,028	37	114	14	547	8,01

a – minimum; minimum b – maksimum; maximum c – średnia arytmetyczna; arithmetic mean d – średnia geometryczna; geometric mean e – mediana; median n – liczba próbek; number of samples

Tabela 4
Table

Parametry statystyczne zawartości pierwiastków chemicznych w osadach

Statistical parameters of chemical elements contents in sediments

Osady Sediments	Parametry Parameters	Ag mg/kg	Al %	As mg/kg	Ba mg/kg	Ca %	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Hg mg/kg	Mg %	Mn mg/kg	Ni mg/kg	P %	Pb mg/kg	S %	Sr mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg
Granica wykrywalności Detection limit		1	0,01	3	1	0,01	0,5	1	1	1	0,01	0,02	0,01	2	1	0,002	2	0,003	1	5	1	1
	a	<1	0,05	<3	7	0,01	<0,5	<1	2	1	0,04	<0,02	<0,01	3	<1	0,004	3	0,003	2	<5	<1	11
Osady (wszystkie próbki)	b	12	5,07	151	1133	4,50	237,7	115	227	736	12,89	12,65	2,09	22 110	320	0,530	13 880	3,290	362	307	140	10 820
Sediments (all samples)	c	<1	0,69	18	213	0,68	9,8	6	19	57	1,45	0,30	0,18	584	17	0,095	444	0,281	30	57	15	919
n = 296	d	<1	0,53	11	148	0,34	4,4	3	12	23	0,94	0,10	0,09	203	10	0,065	183	0,143	19	45	11	437
	e	<1	0,59	10	168	0,34	4,3	3	11	21	1,02	0,10	0,08	232	10	0,074	178	0,159	19	44	13	423
	a	<1	0,05	<3	16	0,01	<0,5	<1	2	2	0,07	<0,02	0,02	7	1	0,004	4	0,003	2	<5	<1	23
Strumienie i rowy bez nazwy	b	10	5,07	151	846	4,50	237,7	41	227	736	3,88	12,65	2,09	3089	185	0,360	4030	2,121	121	307	41	6009
Streams and ditches (without a name)	c	1	0,71	18	211	0,87	11,6	5	26	86	1,23	0,46	0,22	368	21	0,093	512	0,304	33	61	14	1072
n = 132	d	<1	0,53	11	157	0,39	4,8	3	17	33	0,93	0,13	0,12	183	13	0,063	210	0,153	22	46	11	493
	e	<1	0,64	11	193	0,41	5,4	4	14	26	1,04	0,12	0,10	234	14	0,074	201	0,176	23	44	13	526
	a	<1	0,16	<3	23	0,03	<0,5	<1	4	2	0,21	<0,02	0,03	25	3	0,006	4	0,015	2	12	4	27
Sadzawki	b	<1	1,16	19	357	3,16	51,1	13	27	56	1,47	0,21	0,44	1607	34	0,098	638	1,152	82	89	33	4274
Small water pools	c	<1	0,58	6	141	0,55	4,9	4	10	18	0,79	0,07	0,10	205	11	0,039	104	0,253	18	48	12	458
n = 19	d	<1	0,51	4	100	0,21	1,7	3	8	12	0,68	0,04	0,07	107	8	0,028	56	0,121	11	43	10	208
	e	<1	0,50	5	102	0,19	2,2	3	7	12	0,66	0,05	0,06	84	7	0,037	69	0,132	12	47	10	212
	a	<1	0,15	<3	11	0,08	<0,5	<1	3	3	0,27	<0,02	0,03	30	3	0,08	3	0,004	3	9	4	13
Stawy	b	<1	1,08	14	290	4,24	4,9	12	24	24	1,85	0,09	2,09	755	30	0,187	401	0,919	63	103	27	656
Ponds	c	<1	0,54	5	139	0,80	1,5	3	9	14	0,79	0,04	0,38	239	11	0,045	80	0,184	17	45	10	153
n = 9	d	<1	0,43	4	89	0,32	0,8	2	7	11	0,62	0,03	0,12	144	8	0,029	34	0,071	11	34	9	86
	e	<1	0,35	4	111	0,25	0,6	2	7	18	0,59	0,03	0,07	95	6	0,026	38	0,067	13	36	7	69
	a	<1	0,06	<3	7	0,24	<0,5	<1	2	2	0,11	<0,02	0,11	50	1	0,006	18	0,006	2	33	2	64
Drama	b	2	1,07	14	243	1,89	6,6	7	20	34	1,78	0,36	0,81	624	18	0,309	430	0,334	45	102	24	908
Drama River	c	<1	0,39	5	68	0,70	2,3	3	9	12	0,72	0,10	0,30	195	7	0,079	138	0,100	14	59	8	379
n = 11	d	<1	0,29	4	45	0,55	1,7	2	7	8	0,53	0,06	0,24	151	5	0,048	93	0,056	10	56	6	291
	e	<1	0,31	4	52	0,48	2,1	2	8	9	0,58	0,07	0,19	150	6	0,052	94	0,056	11	60	7	304
	a	<1	0,11	<3	20	0,08	0,8	1	3	2	0,26	<0,02	0,03	143	3	0,015	191	0,010	3	66	3	136
Rzepecki Rów	b	12	0,81	148	224	2,35	108,0	8	42	52	9,01	0,22	0,95	2492	39	0,310	13 880	0,320	51	175	39	9010
Rzepecki Rów Stream	c	3	0,56	38	114	1,01	19,2	5	19	25	2,67	0,11	0,38	1006	17	0,118	2638	0,102	25	108	18	2125
n = 11	d	1	0,49	15	87	0,54	6,9	4	14	15	1,66	0,07	0,21	734	13	0,082	1156	0,056	17	102	14	1018
	e	<1	0,67	21	139	0,62	4,6	6	16	19	2,11	0,11	0,22	611	18	0,102	775	0,081	23	90	20	769
	a	<1	0,06	<3	7	0,08	<0,5	<1	2	2	0,11	<0,02	0,03	30	1	0,006	3	0,004	2	17	2	13
Zlewnia Dramy	b	12	1,10	148	334	2,92	108,0	15	42	73	9,01	0,36	1,42	2492	39	0,530	13 880	0,600	64	175	39	9010
Drama River catchment	c	<1	0,52	13	112	0,69	6,0	4	13	17	1,29	0,08	0,26	578	12	0,092	698	0,093	19	74	13	732
n = 54	d	<1	0,43	6	82	0,46	2,4	3	10	12	0,90	0,06	0,17	338	9	0,061	174	0,058	14	67	10	346
	e	<1	0,48	6	112	0,34	2,2	4	10	12	1,00	0,07	0,14	380	10	0,069	143	0,053	14	66	12	332
	a	<1	0,14	<3	30	0,07	1,3	<1	2	2	0,35	<0,02	0,02	43	3	0,016	40	0,033	7	13	2	189
Pniowiec	b	2	1,73	46	358	2,32	54,5	115	26	61	8,58	0,58	0,86	22 110	78	0,240	825	1,370	55	181	35	6925
Pniowiec Stream	c	<1	0,53	15	191	0,50	10,8	12	8	19	1,77	0,10	0,11	2376	17	0,082	223	0,339	19	43	10	1280
n = 23	d	<1	0,42	10	163	0,34	6,2	6	7	13	1,26	0,06	0,07	479	11	0,069	171	0,213	16	37	8	738
	e	<1	0,38	9	187	0,29	4,1	5	7	14	1,31	0,05	0,06	294	8	0,074	172	0,232	14	34	8	454
	a	<1	0,14	<3	15	0,01	<0,5	<1	2	1	0,04	<0,02	<0,01	3	<1	0,005	3	0,004	2	<5	2	11
Zlewnia Pniowca	b	5	3,82	110	1133	3,52	111,8	115	102	482	12,89	2,34	0,86	22 110	320	0,340	1551	3,290	362	248	140	10 820
Pniowiec Stream catchment	c	<1	0,75	21	265	0,45	9,4	7	13	43	1,79	0,20	0,08	847	14	0,099	238	0,346	30	43	18	828
n = 110	d	<1	0,58	13	184	0,25	5,3	3	9	21	0,96	0,10	0,05	179	8	0,071	159	0,207	20	36	12	423
	e	<1	0,56	13	209	0,24	5,0	3	9	22	1,04	0,11	0,05	157	8	0,076	172	0,215	19	37	11	400
	a	<1	0,05	7	48	0,18	3,1	<1	9	36	0,28	0,07	0,02	55	4	0,016	258	0,104	23	19	<1	679
Stoła	b	10	1,05	151	609	3,66	237,7	12	227	736	3,88	12,65	0,99	1670	185	0,360	4030	1,829	121	169	29	6009
Stoła River	c	2	0,41	32	286	1,41	21,9	4	53	215	1,69	1,23	0,36	493	37	0,163	1195	0,523	59	88	11	2289
n = 42	d	2	0,31	26	237	1,02	15,1	3	44	175	1,39	0,55	0,23	362	24	0,134	936	0,384	55	76	8	2040
	e	2	0,29	23	289	1,00	15,5	4	45	171	1,36	0,45	0,22	332	20	0,161	988	0,369	55	85	9	2188

Tabela 4 cd.
Table 4 cont.

Osady Sediments	Parametry Parameters	Ag mg/kg	Al %	As mg/kg	Ba mg/kg	Ca %	Cd mg/kg	Co mg/kg	Cr mg/kg	Cu mg/kg	Fe %	Hg mg/kg	Mg %	Mn mg/kg	Ni mg/kg	P %	Pb mg/kg	S %	Sr mg/kg	Ti mg/kg	V mg/kg	Zn mg/kg
Zlewnia Stoły Stoła River catchment n = 132	a	<1	0,05	<3	16	0,01	<0,5	<1	2	2	0,07	<0,02	0,02	7	1	0,004	4	0,003	2	<5	<1	23
	b	10	5,07	151	846	4,50	237,7	41	227	736	3,88	12,65	2,09	3089	185	0,360	4030	2,121	121	307	41	6009
	c	1	0,71	18	211	0,87	11,6	5	26	86	1,23	0,46	0,22	368	21	0,093	512	0,304	33	61	14	1072
	d	<1	0,53	11	157	0,39	4,8	3	17	33	0,93	0,13	0,12	183	13	0,063	210	0,153	22	46	11	493
	e	<1	0,64	11	193	0,41	5,4	4	14	26	1,04	0,12	0,10	234	14	0,074	201	0,176	23	44	13	526
Tło geochemiczne; geochemical background																						
Osady strumieniowe Europy [1] Stream sediments of Europe n = 794	e		10,4	6	87,5	2,44	0,29	8	22	15	1,97	0,04	0,72	453	17	0,056	14	0,050	124	3800	29	60
Osady Polski [2] Sediments of Poland n = 12 778	e	<1		<5	54	0,86	<0,5	3	5	7	0,80	0,05	0,11	274	6	0,059	13	0,040	20	30	7	62
Osady regionu śląsko-krakowskiego [3] Sediments of Cracow-Silesia Region n = 1459	e	1		6	98	0,71	2,5	4	9	15	1,07	0,06	0,13	292	11	0,066	59	0,052	24	42	12	259

a – minimum; minimum b – maksimum; maximum c – średnia arytmetyczna; arithmetic mean d – średnia geometryczna; geometric mean e – mediana; median n – liczba próbek; number of samples [1] Salminen i in., 2005; [2] Lis, Pasieczna, 1995a; [3] Lis, Pasieczna, 1995b

Tabela 5
Table

Parametry statystyczne przewodności elektrolitycznej właściwej, odczynu i zawartości pierwiastków chemicznych w wodach powierzchniowych

Statistical parameters of electrolytic conductivity, acidity and chemical elements contents in surface water

Wody powierzchniowe Surface water	Parametry Parameters	EC mS/cm	pH	Ag µg/dm³	Al µg/dm³	As µg/dm³	B mg/dm³	Ba mg/dm³	Be µg/dm³	Ca mg/dm³	Cd µg/dm³	Co µg/dm³	Cr mg/dm³	Cu µg/dm³	Fe mg/dm³
Granica wykrywalności Detection limit				0,05	0,5	2	0,01	0,001	0,05	0,1	0,05	0,05	0,003	0,05	0,01
Wody powierzchniowe (wszystkie próbki) Surface water (all samples) n = 219	a	0,08	4,7	<0,05	3,2	<2	0,01	0,019	<0,05	4,3	<0,05	<0,05	<0,003	0,32	0,01
	b	1,70	8,5	0,06	4035,3	27	16,71	1,338	3,01	183,9	20,49	38,86	0,008	41,72	16,77
	c	0,65	7,2	<0,05	159,7	3	1,02	0,167	0,09	66,3	0,69	1,73	<0,003	1,99	0,72
	d	0,53	7,2	<0,05	30,1	<2	0,14	0,116	<0,05	56,1	0,11	0,41	<0,003	1,22	0,14
	e	0,53	7,2	<0,05	18,9	<2	0,08	0,116	<0,05	61,9	0,11	0,43	<0,003	1,10	0,11
Strumienie i rowy (bez nazwy) Streams and ditches (without a name) n = 105	a	0,10	4,7	<0,05	5,8	<2	0,01	0,019	<0,05	4,3	<0,05	<0,05	<0,003	0,34	0,01
	b	1,70	8,0	0,06	4035,3	27	1,22	0,462	3,01	141,4	20,49	38,86	0,007	24,41	16,77
	c	0,53	7,0	<0,05	290,3	2	0,15	0,137	0,15	59,3	1,16	2,81	<0,003	1,98	1,25
	d	0,43	6,9	<0,05	51,3	<2	0,08	0,112	0,06	49,1	0,18	0,59	<0,003	1,32	0,23
	e	0,43	7,1	<0,05	31,0	<2	0,08	0,116	<0,05	54,3	0,10	0,49	<0,003	1,24	0,16
Sadzawki Small water pools n = 20	a	0,08	5,2	<0,05	5,0	<2	0,01	0,031	<0,05	5,7	<0,05	<0,05	<0,003	0,32	0,01
	b	1,52	8,5	<0,05	962,9	4	0,65	0,792	0,89	183,9	4,04	6,22	0,004	4,68	3,72
	c	0,40	7,3	<0,05	111,3	<2	0,10	0,189	0,09	47,4	0,24	0,62	<0,003	1,02	0,56
	d	0,31	7,3	<0,05	29,3	<2	0,07	0,134	<0,05	31,4	<0,05	0,19	<0,003	0,80	0,13
	e	0,33	7,4	<0,05	18,4	<2	0,07	0,111	<0,05	40,8	<0,05	0,18	<0,003	0,70	0,12
Stawy Ponds n = 9	a	0,33	6,7	<0,05	7,1	<2	0,02	0,054	<0,05	10,3	<0,05	<0,05	<0,003	0,46	0,01
	b	1,34	8,3	<0,05	107,3	4	0,12	0,372	<0,05	55,8	0,06	1,35	<0,003	1,41	1,09
	c	0,51	7,3	<0,05	23,7	<2	0,07	0,141	<0,05	44,0	<0,05	0,20	<0,003	0,75	0,14
	d	0,47	7,3	<0,05	16,3	<2	0,06	0,120	<0,05	40,2	<0,05	0,06	<0,003	0,68	0,03
	e	0,41	7,2	<0,05	14,4	<2	0,06	0,131	<0,05	48,7	<0,05	<0,05	<0,003	0,55	0,02
Drama Drama River n = 11	a	0,79	7,0	<0,05	3,2	<2	0,04	0,019	<0,05	76,6	<0,05	<0,05	<0,003	0,68	0,01
	b	1,18	7,8	<0,05	25,1	3	0,70	0,121	<0,05	120,4	0,28	0,83	<0,003	4,88	0,22
	c	0,97	7,4	<0,05	12,9	<2	0,12	0,053	<0,05	100,7	0,13	0,29	<0,003	1,13	0,06
	d	0,95	7,4	<0,05	10,0	<2	0,07	0,047	<0,05	99,3	0,09	0,13	<0,003	0,89	0,03
	e	1,03	7,4	<0,05	11,1	<2	0,07	0,055	<0,05	112,5	0,11	0,29	<0,003	0,74	0,03
Rzepecki Rów Rzepecki Rów Stream n = 11	a	0,43	6,3	<0,05	5,7	<2	0,04	0,038	<0,05	58,4	<0,05	<0,05	<0,003	0,67	0,02
	b	0,93	8,3	<0,05	23,0	3	0,13	0,112	<0,05	91,9	0,15	0,40	<0,003	1,99	0,24
	c	0,74	7,6	<0,05	13,4	<2	0,08	0,053	<0,05	78,9	0,07	0,10	<0,003	1,19	0,06
	d	0,71	7,5	<0,05	12,4	<2	0,07	0,051	<0,05	77,8	0,06	0,06	<0,003	1,15	0,04
	e	0,86	8,0	<0,05	12,3	<2	0,07	0,050	<0,05	84,5	0,06	0,05	<0,003	1,11	0,03
Zlewnia Dramy Drama River catchment n = 45	a	0,38	6,3	<0,05	3,2	<2	0,02	0,019	<0,05	41,8	<0,05	<0,05	<0,003	0,51	0,01
	b	1,70	8,3	<0,05	75,1	6	0,71	0,197	0,13	141,4	4,05	3,78	<0,003	24,4	0,28
	c	0,81	7,4	<0,05	15,9	<2	0,09	0,070	<0,05	87,5	0,25	0,32	<0,003	1,65	0,07
	d	0,76	7,4	<0,05	12,7	<2	0,07	0,061	<0,05	84,7	0,08	0,12	<0,003	1,07	0,04
	e	0,79	7,3	<0,05	12,7	<2	0,06	0,055	<0,05	84,5	0,05	0,10	<0,003	0,90	0,05
Pniowiec Pniowiec Stream n = 23	a	0,19	6,9	<0,05	5,5	<2	0,03	0,061	<0,05	20,4	<0,05	<0,05	<0,003	0,35	0,03
	b	0,62	7,9	<0,05	208,5	6	0,15	0,260	0,24	76,5	0,13	3,76	<0,003	1,42	1,91
	c	0,49	7,3	<0,05	25,8	<2	0,09	0,134	<0,05	59,7	<0,05	0,73	<0,003	0,60	0,40
	d	0,48	7,3	<0,05	14,7	<2	0,08	0,120	<0,05	58,1	<0,05	0,35	<0,003	0,54	0,27
	e	0,50	7,3	<0,05	11,9	<2	0,09	0,152	<0,05	60,6	<0,05	0,54	<0,003	0,51	0,24
Zlewnia Pniowca Pniowiec Stream catchment n = 76	a	0,10	4,7	<0,05	5,5	<2	0,01	0,058	<0,05	7,5	<0,05	<0,05	<0,003	0,34	0,01
	b	1,48	8,5	0,06	4035,3	27	1,22	0,792	0,89	129,6	20,49	23,00	0,007	4,68	16,77
	c	0,41	7,0	<0,05	230,8	2	0,18	0,182	0,09	45,7	0,76	2,52	<0,003	0,98	1,54
	d	0,36	7,0	<0,05	40,5	<2	0,11	0,157	<0,05	39,5	0,09	0,50	<0,003	0,81	0,42
	e	0,41	7,2	<0,05	17,2	<2	0,12	0,154	<0,05	49,0	<0,05	0,52	<0,003	0,72	0,39

Wody powierzchniowe Surface water	Parametry Parameters	K mg/dm³	Li µg/dm³	Mg mg/dm³	Mn mg/dm³	Mo µg/dm³	Na mg/dm³	Ni µg/dm³	P mg/dm³	Pb µg/dm³	SO_4 mg/dm³	Sb µg/dm³	Se µg/dm³	SiO_2 mg/dm³	Sr mg/dm³	Ti mg/dm³	Tl µg/dm³	U µg/dm³	V µg/dm³	Zn mg/dm³
Granica wykrywalności Detection limit		0,5	0,3	0,1	0,001	0,05	0,5	0,5	0,05	0,05	1	0,05	2	0,1	0,003	0,002	0,05	0,05	1	0,003
Wody powierzchniowe (wszystkie próbki) Surface water (all samples) n = 219	a	<0,5	<0,3	1,1	0,001	<0,05	<0,5	<0,5	<0,05	<0,05	2	<0,05	<2	0,2	0,015	<0,002	<0,05	<0,05	<1	<0,003
	b	112,4	146,8	115,6	16,221	113,64	175,7	606,9	29,35	31,61	710	2,26	2	25,9	0,998	0,006	0,66	2,53	10	4,713
	c	9,1	8,7	15,4	0,429	2,63	35,6	14,0	0,53	1,54	85	0,32	<2	10,7	0,240	<0,002	0,09	0,39	1	0,140
	d	5,2	5,4	11,9	0,160	0,51	18,3	2,8	0,10	0,50	62	0,25	<2	8,2	0,194	<0,002	0,06	0,20	<1	0,027
	e	4,6	4,8	12,4	0,204	0,42	16,0	2,2	<0,05	0,45	66	0,26	<2	11,4	0,188	<0,002	<0,05	0,29	<1	0,026
Strumienie i rowy (bez nazwy) Streams and ditches (without a name) n = 105	a	<0,5	0,7	1,1	0,001	<0,05	0,4	<0,5	<0,05	<0,05	3	0,06	<2	0,6	0,015	<0,002	<0,05	<0,05	1	<0,003
	b	112,4	59,7	67,0	16,221	113,64	175,7	107,6	29,35	31,61	615	1,07	2	25,9	0,897	0,006	0,53	2,14	10	4,713
	c	8,5	5,7	13,0	0,586	1,64	23,3	5,7	0,66	2,28	72	0,32	<2	11,1	0,197	<0,002	0,08	0,36	1	0,213
	d	4,0	4,4	9,6	0,193	0,31	11,6	2,7	0,07	0,59	53	0,26	<2	9,2	0,168	<0,002	0,05	0,14	<1	0,038
	e	3,1	4,4	10,0	0,215	0,34	13,0	2,4	<0,05	0,44	51	0,25	<2	10,7	0,175	<0,002	<0,05	0,21	<1	0,035
Sadzawki Small water pools n = 20	a	<0,5	<0,3	1,2	0,002	<0,05	1,5	<0,5	<0,05	<0,05	2	0,05	<2	0,3	0,031	<0,002	<0,05	<0,05	<1	<0,003
	b	25,9	63,5	115,6	0,594	1,56	66,6	11,8	1,11	4,29	710	2,26	<2	13,7	0,703	0,004	0,66	2,53	2	0,793
	c	5,6	6,3	15,6	0,202	0,37	9,8	1,9	0,14	0,85	86	0,33	<2	3,8	0,158	<0,002	0,07	0,25	<1	0,056
	d	3,9	2,8	7,9	0,100	0,17	6,1	1,0	0,06	0,40	35	0,23	<2	2,1	0,121	<0,002	<0,05	0,09	<1	0,009
	e	4,3	2,8	9,4	0,177	0,25	5,3	1,0	<0,05	0,43	25	0,22	<2	1,9	0,115	<0,002	<0,05	0,08	<1	0,006
Stawy Ponds n = 9	a	2,0	1,9	3,1	0,001	0,06	4,8	<0,5	<0,05	<0,05	11	0,11	<2	0,2	0,051	<0,002	<0,05	<0,05	<1	<0,003
	b	14,0	9,0	19,6	0,709	1,00	15,4	2,3	0,37	2,36	60	0,28	<2	4,3	0,188	<0,002	<0,05	1,24	1	0,113
	c	5,0	4,8	12,7	0,162	0,46	11,3	1,5	0,07	0,35	35	0,18	<2	1,5	0,143	<0,002	<0,05	0,44	<1	0,015
	d	4,0	4,5	11,3	0,034	0,35	10,5	1,3	<0,05	0,10	29	0,17	<2	1,0	0,133	<0,002	<0,05	0,25	<1	0,003
	e	3,7	4,8	11,4	0,048	0,43	13,0	1,5	<0,05	0,09	45	0,17	<2	0,6	0,162	<0,002	<0,05	0,33	<1	<0,003
Drama Drama River n = 11	a	2,9	4,0	18,2	0,009	0,36	21,2	<0,5	<0,05	0,30	96	<0,05	<2	10,6	0,208	<0,002	<0,05	0,22	<1	0,004
	b	24,6	56,8	28,7	0,721	24,56	111,5	228,3	1,39	1,94	151	0,63	2	15,2	0,295	<0,002	0,24	0,93	2	0,163
	c	12,2	10,5	25,2	0,138	2,70	61,1	21,9	0,43	0,83	110	0,25	<2	13,5	0,254	<0,002	0,15	0,67	1	0,080
	d	8,3	7,0	25,0	0,048	0,70	46,9	1,5	0,16	0,74	109	0,11	<2	13,4	0,251	<0,002	0,11	0,59	<1	0,047
	e	15,5	5,7	25,1	0,054	0,59	42,7	1,6	0,23	0,81	106	0,22	<2	13,6	0,271	<0,002	0,12	0,88	<1	0,120
Rzepecki Rów Rzepecki Rów Stream n = 11	a	2,3	3,3	8,6	0,012	0,06	12,3	1,1	<0,05	<0,05	68	<0,05	<2	3,5	0,164	<0,002	<0,05	<0,05	<1	0,007
	b	13,0	6,8	14,4	0,385	2,00	78,2	4,7	1,20	4,62	161	0,67	<2	16,9	0,233	<0,002	0,47	0,49	2	0,050
	c	9,2	4,1	11,8	0,098	0,70	53,9	1,7	0,31	1,43	91	0,39	<2	11,6	0,210	<0,002	0,12	0,34	1	0,020
	d	8,4	3,9	11,6	0,056	0,54	46,6	1,5	0,21	0,91	89	0,33	<2	10,8	0,209	<0,002	0,09	0,28	1	0,016
	e	10,4	3,6	12,5	0,047	0,55	68,1	1,4	0,26	1,28	87	0,40	<2	12,5	0,226	<0,002	0,08	0,41	1	0,014
Zlewnia Dramy Drama River catchment n = 45	a	2,0	0,8	7,6	0,008	0,06	5,4	<0,5	<0,05	<0,05	11	<0,05	<2	0,2	0,124	<0,002	<0,05	<0,05	<1	<0,003
	b	104,7	56,8	46,6	1,367	113,6	132,5	228,3	29,32	8,52	170	0,67	2	25,9	0,426	0,003	0,47	1,73	5	0,422
	c	12,8	5,9	18,9	0,136	3,68	45,5	7,2	1,18	1,08	90	0,28	<2	11,8	0,249	<0,002	0,10	0,53	1	0,051
	d	8,6	4,5	17,1	0,057	0,57	33,2	1,6	0,16	0,63	84	0,18	<2	9,6	0,241	<0,002	0,07	0,38	<1	0,022
	e	9,6	4,2	18,6	0,055	0,54	26,0	1,6	0,23	0,77	88	0,29	<2	12,8	0,230	<0,002	0,07	0,49	<1	0,018
Pniowiec Pniowiec Stream n = 23	a	1,5	2,3	5,3	0,058	<0,05	5,7	0,9	<0,05	<0,05	32	<0,05	<2	7,4	0,072	<0,002	<0,05	<0,05	<1	<0,003
	b	8,4	6,7	15,5	3,800	0,49	34,0	8,1	0,47	1,08	81	0,24	<2	17,0	0,212	<0,002	0,10	0,46	1	0,069
	c	4,0	5,2	11,9	0,474	0,29	18,6	2,4	0,09	0,19	56	0,14	<2	11,7	0,174	<0,002	<0,05	0,25	<1	0,013
	d	3,6	5,1	11,6	0,288	0,26	17,2	1,9	0,05	0,14	54	0,13	<2	11,4	0,171	<0,002	<0,05	0,20	<1	0,007
	e	2,8	5,4	12,0	0,281	0,31	17,0	1,6	<0,05	0,14	53	0,15	<2	11,4	0,183	<0,002	<0,05	0,25	<1	0,005
Zlewnia Pniowca Pniowiec Stream catchment n = 76	a	<0,5	<0,3	1,1	0,006	<0,05	1,5	<0,5	<0,05	<0,05	8	<0,05	<2	0,4	0,035	<0,002	<0,05	<0,05	<1	<0,003
	b	15,9	10,1	28,4	16,221	2,48	96,7	42,0	0,47	31,61	185	2,26	<2	22,8	0,403	0,004	0,53	1,32	10	4,713
	c	3,0	4,9	9,0	0,691	0,41	14,1	3,9	0,08	1,57	48	0,30	<2	9,6	0,161	<0,002	0,06	0,18	1	0,196
	d	2,4	4,5	7,6	0,265	0,28	10,0	2,0	<0,05	0,34	43	0,22	<2	7,1	0,148	<0,002	<0,05	0,10	<1	0,021
	e	2,4	4,9	10,1	0,248	0,34	13,5	1,6	<0,05	0,22	46	0,21	<2	9,9	0,168	<0,002	<0,05	0,11	<1	0,017

Tabela 5 cd.
Table 5 cont.

Wody powierzchniowe Surface water	Parametry Parameters	EC mS/cm	pH	Ag µg/dm³	Al µg/dm³	As µg/dm³	B mg/dm³	Ba mg/dm³	Be µg/dm³	Ca mg/dm³	Cd µg/dm³	Co µg/dm³	Cr mg/dm³	Cu µg/dm³	Fe mg/dm³	K mg/dm³	Li µg/dm³	Mg mg/dm³	Mn mg/dm³	Mo µg/dm³	Na mg/dm³	Ni µg/dm³	P mg/dm³	Pb µg/dm³	SO_4 mg/dm³	Sb µg/dm³	Se µg/dm³	SiO_2 mg/dm³	Sr mg/dm³	Ti mg/dm³	Tl µg/dm³	U µg/dm³	V µg/dm³	Zn mg/dm³
	a	0,26	6,8	<0,05	8,5	<2	0,04	0,032	<0,05	38,2	<0,05	<0,05	<0,003	0,38	0,01	<0,5	2,4	7,4	0,001	0,19	4,3	1,0	<0,05	<0,05	5	<0,05	<2	4,1	0,121	<0,002	<0,05	<0,05	<1	0,008
Stoła Stoła River	b	1,44	7,9	<0,05	131,8	20	16,71	1,338	<0,05	116,1	11,75	6,98	<0,003	41,72	0,49	31,0	146,8	29,9	0,925	23,69	116,0	606,9	4,56	4,28	198	1,01	2	17,1	0,998	<0,002	0,54	0,98	2	1,696
	c	1,11	7,4	<0,05	30,6	6	5,40	0,344	<0,05	89,7	0,58	1,31	<0,003	4,43	0,11	16,4	23,0	21,8	0,356	9,32	88,2	56,5	0,78	1,22	139	0,51	<2	13,3	0,478	<0,002	0,16	0,54	<1	0,147
n = 37	d	1,07	7,4	<0,05	24,4	4	2,17	0,211	<0,05	87,1	0,15	1,04	<0,003	2,83	0,07	13,7	15,0	21,1	0,246	5,75	76,5	13,6	0,43	0,83	123	0,45	<2	13,0	0,398	<0,002	0,10	0,48	<1	0,063
	e	1,17	7,5	<0,05	22,4	7	2,91	0,145	<0,05	86,3	0,13	1,17	<0,003	2,46	0,08	15,9	13,4	22,8	0,243	9,63	95,6	10,4	0,42	1,03	148	0,54	<2	14,3	0,401	<0,002	0,08	0,46	<1	0,050
	a	0,08	4,8	<0,05	5,0	<2	0,01	0,025	<0,05	4,3	<0,05	<0,05	<0,003	0,32	0,01	<0,5	0,5	1,3	0,001	<0,05	0,4	<0,5	<0,05	<0,05	2	<0,05	<2	0,3	0,015	<0,002	<0,05	<0,05	<1	0,003
Zlewnia Stoły Stoła River catchment	b	1,52	8,3	<0,05	3905,3	20	16,71	1,338	3,01	183,9	11,75	38,86	0,008	41,72	8,60	112,4	146,8	115,6	3,175	23,69	175,7	606,9	6,24	22,36	710	1,01	2	22,9	0,998	0,006	0,66	2,53	5	1,696
	c	0,76	7,2	<0,05	170,6	4	2,09	0,199	0,12	72,6	0,84	1,77	<0,003	2,94	0,40	12,2	13,0	18,7	0,361	3,87	47,8	25,1	0,58	1,73	110	0,37	<2	11,1	0,298	<0,002	0,11	0,50	1	0,138
n = 98	d	0,62	4,2	<0,05	35,4	2	0,23	0,124	<0,05	60,8	0,15	0,62	<0,003	1,77	0,10	7,6	6,8	14,2	0,173	0,78	22,3	4,76	0,15	0,60	73	0,30	<2	8,6	0,215	<0,002	0,07	0,26	<1	0,035
	e	0,75	7,3	<0,05	22,8	<2	0,09	0,113	<0,05	75,8	0,10	0,83	<0,003	1,86	0,08	8,8	6,1	18,4	0,226	0,76	32,5	4,25	0,13	0,49	91	0,32	<2	12,2	0,198	<0,002	0,06	0,39	<1	0,040
Wartości wskaźników jakości wód powierzchniowych i pitnych; surface water and drinking water quality guidelines																																		
I klasa [1] Class I		≤0,36	7,5–8,2	≤5	≤400	≤50	≤2	≤0,5	≤0,8	≤68,3	0,5	≤50	≤0,05	≤50	0,1			≤5		≤40		10	≤0,18	10	≤31,6	≤2	≤20			≤0,05	≤2		≤50	≤1
II klasa [1] Class II		≤0,45	7,3–8,2							≤76,2	1				0,3			≤7,8				20	≤0,22	10	≤37,7									
Naturalne wody mineralne [2] Natural Mineral Water						10		1			3		0,05						500			20		10		5	10							
Wody pitne [3] Drinking Water		2,5	≥6,5–9,5≤		200	10	1				5		0,05						50		200	20		10	250	5	10							

a – minimum; minimum b – maksimum; maximum c – średnia arytmetyczna; arithmetic mean d – średnia geometryczna; geometric mean e – mediana; median n – liczba próbek; number of samples

[1] Wartości wskaźników jakości wód powierzchniowych w Polsce; surface water quality guidelines in Poland (Rozporządzenie..., 2019)

[2] Naturalne wody mineralne; Natural Mineral Water (EU Directive 2009/54/EC Natural Mineral Water)

[3] Wody pitne; Drinking Water (EU Directive 1998/83/EC Drinking Water)

Acidity. The pH variability of the soils is related largely to the way they are used, which, in turn, is constrained by the bedrock lithology. About 1/3 of the study area is covered by forest soils that are characterized by a highly acidic or moderately acidic pH (Pls. 7 and 8). Greater acidification was observed in the topsoil (average pH 4.61) compared to the subsoil (average pH 5.99) (Tabs. 2 and 3). In the southwestern part of the map sheet area, neutral and locally acidic soils prevail, with similar extents in both depth ranges.

The soils of urban and industrial districts of Tarnowskie Góry are alkaline. The alkalinity is more widespread in the subsoil, which indicates that alkalization can be associated primarily with their development on Triassic carbonates. In turn, one of the causes of high pH of the topsoil is the dispersion of dust from the combustion of coal over many years. The coal ash contains an average of 14,200 mg/kg calcium (Kalembasa *et al.*, 2008). Other alkalizing factors include street clearing agents, periodic dusting from mining and smelting waste heaps, and scattering of Triassic limestones and dolomites mined in nearby quarries. The alkaline reaction of soils in urban and industrial areas is also influenced by admixtures of building materials containing calcium (plasters, cements, paints).

Geochemistry. The spatial distribution of elements in the soils indicates both their strong relationship with the chemical composition of parent rocks in the bedrock and the influence of land use on the pollution with potentially toxic elements.

The soils that developed on Pleistocene glaciofluvial sands and are characterized by the sand fraction content, sometimes exceeding 90%, contain the smallest amounts of the analyzed elements. This applies to both topsoil and subsoil. The low contents of the elements in these soils are related to the poor chemical composition of the bedrock and the acidic pH, which make them easy to leach. The soils that developed on Triassic carbonates are distinguished by higher contents, especially of calcium and magnesium, and abundance in iron and manganese.

In the areas of Zn-Pb ore mining and processing, near industrial waste heaps and in urban areas, the chemical composition of soils is significantly altered compared to natural soils.

In the topsoil, the content of most of the elements (cobalt, chromium, copper, iron, magnesium, manganese, nickel, phosphorus, strontium, titanium and vanadium), which are sourced mainly from the parent rocks, does not differ from the geochemical background value of the Silesian-Cracow region, expressed as their medians (Tab. 2). Approximately twofold depletion was recorded in the case of calcium, which is associated with the predominance of sandy soils containing small amounts of its compounds. It is also found that the soils contain twice as much of barium. The median value of the content of potentially toxic elements (cadmium and zinc) remains at the geochemical background level for the region, while distinct pollution (almost threefold enrichment) is recorded only in the case of lead.

In the southern part of the map sheet area, where outcrops of Triassic carbonates and Quaternary tills predominate, both topsoil and subsoil usually contain 0.40–0.80% of aluminum. In the northern part of the map sheet area, the soils developed on glacial sands and gravels are poor in aluminum (<0.40%). The high acidification is probably the main factor causing leaching of aluminum and, as a result, its accumulation in sediments and waters of this region (Pls. 11 and 12).

The organic carbon content in the topsoil layer (0.0–0.3 m) is in the range of 0.15–48.60% (Tab. 2). The smallest amounts of organic carbon (<3%) are measured in soils of the southwestern part of the map sheet area. More than 12% of organic carbon was recorded in soils near railway stations and tracks in the Płuczki-Czarna Huta area, which is certainly related to dispersion of coal particles during many years of its transport.

In most of the soils from both depth intervals, the sulfur content does not exceed 0.080%. More than 0.160% of sulfur was found near the Chemical Plant ZCH Tarnowskie Góry waste landfill and in organic matter-rich soils of some forests, which is expressed in the abundance of organic carbon.

The phosphorus content is higher in topsoil than in subsoil (median values are 0.074% and 0.008%, respectively). In the topsoil of the southern area, the phosphorus content is 0.030–0.120%, whereas most of the soils in northern forests contain <0.030%. A similar pattern of spatial distribution of the phosphorus content is observed in the subsoil, although the levels in the south are slightly lower and more varied.

The natural distribution of the content of many of the analyzed elements in the soils is influenced by anthropogenic factors. The most important are as follows: historical exploitation, processing and rail transport of Zn-Pb ores from the Bobrowniki region to the Fryderyk smelter in Strzybnica, the impact of leachates and dusts from tailings heaps, many-year production processes, storage and dispersion of toxic substances produced in the Chemical Plant ZCH Tarnowskie Góry, sewage and waste from other industrial plants (including metal and machine plants, galvanizing plants and electroplating plants), as well as urbanization and transport.

The above-mentioned anthropogenic factors largely influenced the distribution of barium, calcium, magnesium and strontium.

In the southeastern part of the map sheet area, the topsoil layer is heavily polluted with barium. The content of this element in the districts of Tarnowskie Góry: Osada Jana, Śródmieście-Centrum, Sowice, Lasowice and Strzybnica, as well as in the forests between the Stoła River and the Pniowiec Stream valleys, is >480 mg/kg. The remarkably larger extent of barium-rich areas in topsoil allows concluding that the barium is of anthropogenic origin. In the subsoil layer, the anomalous barium content is limited to much smaller areas in the centre of Tarnowskie Góry and in its district of Strzybnica. The maximum barium content in the topsoil layer (47,151 mg/kg) was recorded in a wooded area on the eastern side of Towarowa Street and around the ZCH Tarnowskie Góry waste landfill (21,733 mg/kg). The barium content exceeding 3,000 mg/kg is also recorded in the soils at Cegielniana Street in Lasowice, Św. Katarzyny Street in Centrum, and near the ZCH Tarnowskie Góry landfill. In subsoil, 63,112 mg/kg of barium was found within an anomaly in the industrial area at Zagórska Street in Strzybnica.

The pollution by barium is related to the storage of waste from the ZCH Tarnowskie Góry, where lithopone, barium chloride, barium nitrate and barium sulfate were produced for several decades (Zakłady..., 2017). Over many years, the waste was deposited in dumps around the plant without any anti-pollution protection of the area, which resulted in the migration of barium and other elements to the environment. Earlier studies from the landfill area reported 400–15,000 mg/kg of barium, 4–1,500 mg/kg of strontium, and 10–120 mg/kg of boron in soils (Bzowski, Dawidowski, 2007).

The presence of anomalies of this element in the soils of Strzybnica is not easy to explain. In the period 1786–1933, the Fryderyk lead and silver foundry operated, and after World War II, machine – building plants (Huta Fryderyk...) existed here, but it is difficult to link the use of barium compounds with this type of industrial production. Waste from the ZCH chemical plant Tarnowskie Góry may have been sent to landfills in Strzybnica at some time.

The topsoil pollution with barium in the Stoła River and Pniowiec Stream valleys significantly increases its content also in sediments and surface waters (Pls. 16 and 17).

Highly increased contents of calcium, magnesium and strontium (>2%, >0.50% and >40 mg/kg, respectively) are found in the layer of subsoil that developed from Triassic limestones and dolomites, and in places of historical extraction of Zn-Pb ore-bearing dolomites (in Bobrowniki and Stare Tarnowice). Enrichment in these elements in the topsoil layer was found at the same locations, but it is less clear. The soils of urban-industrial areas of the eastern part of the map sheet, as well as those adjacent to the Bobrowniki-Strzybnica railway line, which for many years transported Zn-Pn ores from Bobrowniki to the Fryderyk foundry, show anthropogenic anomalies. The enrichments in calcium and magnesium can be associated with the dispersion of waste from the mining of ores in carbonate rocks and alkaline dust from fuel combustion, as well as with the admixture of building materials in soils.

The strongest strontium anomalies (>320 mg/kg) in the topsoil in the ZCH Tarnowskie Góry waste landfill area and in the subsoil in Strzybnica are associated with the production of these industrial plants and the dispersion of strontium compounds into the environment (as with the case of barium), which were used as reagents in production processes.

Other elements whose content in soils is related both to their presence in the parent material and the influence of anthropogenic factors are iron and manganese. Their spatial distribution is similar in both soil depth intervals, and the lowest contents are found in sandy soils of forests in the north of the map sheet area (<0.50% iron and <200 mg/kg manganese, respectively). In the southwestern part, iron was usually recorded in the range of 0.50–2.00%, and manganese from 200 mg/kg to 800 mg/kg. Near waste heaps, local increases in the content of both elements are associated probably with the weathering of Zn-Pb ore-bearing dolomite waste rich in decomposing iron sulfides (Migaszewski, Gałuszka, 2016).

The spatial distributions of cobalt, chromium, nickel, titanium and vanadium are similar to that of iron and manganese, which indicates the bedrock as their primary source.

The copper content anomalies indicate anthropogenic origin of the copper and are probably the result of the production of copper sulfate by the ZCH Tarnowskie Góry (Majer, 2004; Zakłady...). Strong copper pollution of the topsoil (>160 mg/kg) was found in the Tarnowskie Góry railway station area, in the ZCH waste landfill site, and in some of alluvial soils in the valley of the Stoła River, whose sediments are also polluted with this element. The maximum content of copper was recorded in the railway area in Lasowice near Fabryczna Street (2,266 mg/kg), in Czarna Huta (1,165 mg/kg), in the Soła valley near the Repeckie sewage treatment plant (1,977 mg/kg), and in the Piaseczna region (1,867 mg/kg). In the western and northern parts of the map sheet, the topsoil usually contains <20 mg/kg of this element, while the subsoil commonly contains <10 mg/kg.

In most of the soils, the mercury content was found to be close to the geochemical background level (<0.10 mg/kg). Slightly increased contents (0.20–0.40 mg/kg) are observed in urbanized districts, near industrial facilities, and in some soils of wetland forests, which may be due to the precipitation of atmospheric dust from fuel combustion (Bojakowska, Sokołowska, 2001; Hławiczka, 2008).

In the areas of mining and processing of Zn-Pb ore deposits, around the sites of historical silver smelting from galena, in the area of the Fryderyk foundry operation, and near heaps and dumps, anthropogenic anomalies of silver, arsenic, cadmium, lead and zinc were found in both topsoil and subsoil.

Local anomalies of silver (>1 mg/kg), arsenic (>40 mg/kg) and cadmium (>8 mg/kg), of similar extents in both depth intervals, were recorded at sites of reclaimed heaps from the mining of Zn-Pb ores in the southeastern part of the map sheet area and in the Stoła River valley.

The most arsenic-polluted topsoil is in the northern edge of the ZCH Tarnowskie Góry waste landfill (997 mg/kg) and in the Stoła River valley near Piaseczna (720 mg/kg).

Cadmium-polluted soils occupy larger areas in the topsoil, and at sites of their anomalies, the pollution intensity is greater in the subsoil layer. In the eastern and central districts of Tarnowskie Góry, the cadmium content levels were often >4 mg/kg, while in the north and west of the map, the contents were <1–2 mg/kg. In topsoil, the values above 60 mg/kg of cadmium were found in the Stoła River valley in the Piaseczna area, in Puferki area, and in the Stoła River valley near Bytomska Street in the Centrum district of Tarnowskie Góry. In the subsoil, more than 100 mg/kg of cadmium was found in Piekary Rudne (near Kopalniana Street) and in the Stoła River valley (near Grodzka Street).

The greatest pollution of soils is due to the accumulation of lead and zinc. The areas of strong anomalies of these elements coincide with arsenic and cadmium anomalies, but they cover much larger areas, especially in topsoil.

The anomalies of lead (>250 mg/kg) and zinc (>1,000 mg/kg) in both topsoil and subsoil cover the following districts/residential areas in the east of the map sheet: Bobrowniki, Kolonia Staszica, Osada Jana, Lyszcze, Kartuszowiec, Centrum, Czarna Huta and Sowice. Along the Stoła River valley, these are the areas of Puferki, Repeckie, Piaseczno and Strzybnica. Comparison of the distribution of these elements in topsoil and subsoil in the study areas (Pls. 46 and 47, and 61 and 62, respectively) shows that the pollution with lead and zinc is typically anthropogenic. Outside the areas of strong anomalies, the predominant level of lead content in the topsoil is 50–100 mg/kg, and of zinc content is 100–250 mg/kg, while in the subsoil layer, these levels are significantly lower.

The topsoil most heavily polluted with lead (>10,000 mg/kg) was found near Rudna and Strzelecka streets in Tarnowskie Góry-Centrum and in the Piaseczna region. The maximum zinc content (37,005 mg/kg) was recorded in soils of the Stoła River valley in the Piaseczna region, and the contents above 7,000 mg/kg were found in soils of the Stoła River upper reach (Puferki residential area) and near Rudna Street, where the value of 24,201 mg/kg was recorded in subsoil.

The widespread occurrence of arsenic, cadmium, lead and zinc compounds in soils from which they can penetrate into waters is the cause of many human diseases in various countries of the world (Kabata-Pendias, Mukherjee, 2007; Kabata-Pendias, Szteke, 2015; Migaszewski, Gałuszka, 2016). Arable soils, widespread especially in the western part of the map sheet area, require special protection. Polluted with potentially harmful elements, the soils may have a negative effect on organisms living in the soil and on food plants. Arsenic, cadmium, mercury and lead deserve special attention from the point of view of transporting pollutants in the food chain and causing health risks (Gruszecka-Kosowska *et al.*, 2020).

Due to the ease of accumulation and the harmful effects of excess arsenic, cadmium, lead and zinc on plants and soil microorganisms, the percentage of the sheet area polluted with these metals to different extents has been estimated (Tab. 6). The soils polluted by arsenic are rare. Its harmful contents (>100 mg/kg) were found in 0.98% of topsoil and 0.46% of subsoil. At some locations, there is significant soil pollution with cadmium, lead and zinc. In the topsoil, 2.25% of soils contain >15 mg/kg of cadmium, 9.47% of soils >600 mg/kg of lead, and 3.45% of soils >2,000 mg/kg of zinc. At a depth of 0.8–1.0, the percentage of soils polluted with these metals decreases and amounts to 1.47% for cadmium, 4.65% for lead, and 1.98% for zinc.

The topsoil has been assessed in terms of the degree of pollution by metals, classifying it into the use groups of I–III and IV based on permissible contents (Rozporządzenie..., 2016). Due to the content of arsenic, barium, chromium, zinc, cadmium, cobalt, copper, nickel, lead and mercury, groups I–III (meeting the conditions of multifunctional use – residential buildings, arable lands and forests) account for 88.27 – 100% of the analyzed soils. Group IV (soils that can only be used for industrial purpose) spans from 0.60% to 4.66% of soils, and those containing toxic amounts of metals are represented by 0.45% – 9.47% of all soils (Tab. 7).

In many cases, the current land use is inappropriate and requires monitoring and reclamation. An example of soil classification (in a cartographic form) with respect to the permissible cadmium content, indicating the appropriate land use (in accordance with Rozporządzenie..., 2016), is presented on the map of the distribution of the content of this element (Pl. 63). Some areas in the southeastern part of the map sheet and in the Stoła River valley, where the cadmium content in soils is >15 mg/kg, should be reclaimed or excluded from use.

SEDIMENTS

Bottom sediments of inland watercourses and stagnant water reservoirs form as a result of sedimentation of mineral and organic suspensions originating from erosion and precipitation from water. Their chemical composition depends on lithology, climate, and the way of management and use of the drainage basin area (Zgłobicki, 2008; Hinwood *et al.*, 2012; Cánovas *et al.*, 2015).

Tabela 6
Table

Udział obszarów zajmowanych przez gleby o różnych zawartościach arsenu, kadmu, cynku i ołowiu na głębokości 0,0−0,3 m i 0,8−1,0 m

Share of areas with various content of arsenic, cadmium, lead and zinc in topsoil (0.0−0.3 m) and subsoil (0.8−1.0 m)

Pierwiastek Element	Zawartość Content mg/kg	Powierzchniowa warstwa gleb Topsoil 0,0−0,3 m Obszar/Area		Podglebie Subsoil 0,8−1,0 m Obszar/Area	
		km²	%	km²	%
As	<10	67,43	81,73	73,74	89,38
	10–25	10,54	12,78	5,75	6,97
	25–50	2,91	3,53	1,98	2,40
	50–100	0,81	0,98	0,64	0,77
	>100	0,81	0,98	0,38	0,46
Cd	<2	57,94	70,22	74,83	90,70
	2–5	16,05	19,47	3,77	4,57
	5–10	4,84	5,86	1,98	2,40
	10–15	1,80	2,18	0,70	0,85
	>15	1,86	2,25	1,21	1,47
Pb	<100	35,85	43,46	70,86	85,89
	100−200	20,72	25,11	3,90	4,73
	200−500	16,25	19,70	3,45	4,18
	500–600	1,86	2,25	0,44	0,54
	>600	7,82	9,47	3,84	4,65
Zn	<300	63,02	76,39	89,30	73,67
	300−500	6,57	7,97	2,17	1,79
	500−1000	6,20	7,52	3,64	3,00
	1000–2000	3,85	4,66	2,48	2,05
	>2000	2,85	3,45	2,40	1,98

Occurrence of increased (usually unnatural) contents of elements in the sediments is mainly the result of economic activity. In industrial, urban and agricultural areas, their accumulation is associated primarily with the finest sediment fraction. The sediments may accumulate potentially harmful trace elements and organic compounds from industrial and municipal wastewater discharged to surface waters, from leachate of waste landfills, and from surface runoff (Ciszewski, 1997, 2002, 2005; Bojakowska *et al.*, 2006; Kozieł, Zglobicki, 2010; Sojka *et al.*, 2013; Cempiel *et al.*, 2014). High concentrations of both heavy metals (zinc, copper, chromium, cadmium, lead, mercury) and persistent organic pollutants may cause their accumulation in the trophic chain to levels that are toxic to aquatic organisms. As a result of biological, chemical and physical processes, harmful components of sediments may be re-released into water (Friese, 2002; Harnischmacher, 2007), and polluted sediments displaced into floodplain terraces cause an increase in concentrations of many substances in soils of river valleys (Ibragimow *et al.*, 2010).

Within the area covered by the sheet, the bottom sediments of the watercourses and reservoirs of the Drama River, Stoła River and Pniowiec Stream catchments were examined; the areas of the catchments are schematically shown in Figure 3.

The concentrations of cobalt, arsenic, nickel and lead in sediments of unpolluted rivers and streams of Poland do not exceed several mg/kg. The cadmium content is below 0.5 mg/kg, and the mercury content is <0.05 mg/kg (Lis, Pasieczna, 1995b). In the map sheet area the contents of these chemical elements are many times higher (Tab. 4).

Drama River and its catchment. The Drama River and its tributaries (Dopływ spod Wilkowic, Dopływ z Laryszowa, and Starotarnowicki Potok streams) drain the southwestern part of the study area. The Drama's uppermost reach is sometimes called the Rzepecki Rów Stream. The river drains the area of Triassic carbonates covered with Quaternary glacial tills and glaciofluvial sands (Pl. 1).

The dominant economy sector in the catchment is agriculture that poses a threat to the aquatic environment due to using chemical fertilizers and pesticides. Other sources of pollution are the discharge of wastewater from the Repty "Veolia" sewage treatment plant, domestic sewage from small farms, and surface runoff from roads. The greatest pollution of sediments by metals, however, is related to the drainage of the area of historical Zn-Pb ore mining in the Repty region (including the former settlement of Srebrna Góra), where the Segiet mine operated in 1830–1927 (Degenhardt, 1870; Geognostische Karte...; Statystyka..., 1928). The exploitation was carried out by means of shallow excavations in an area of approximately 0.7 km² (Pradela, Solarski, 2013). During several decades, the Drama River also received water from the Fryderyk Zn-Pb ore mine in Bobrowniki through the adits (Piernikarczyk, 1933).

The results of chemical analyses of aluminum, barium, calcium, cobalt, magnesium, nickel, phosphorus, sulfur, strontium and vanadium in the Drama River drainage basin sediments are similar to the values defined as the geochemical background level in the Silesian-Cracow region (Tab. 4).

The aluminum content is most often in the range of 0.27–0.73%, and locally exceeds 1%. The arsenic content in most of the drainage basin sediments is within the natural level (4–10 mg/kg). In some sediments of the upper Drama River (Rzepecki Rów Stream), the arsenic concentration is 70–75 mg/kg, with a maximum of 148 mg/kg.

The calcium and magnesium concentrations are highly variable, ranging from 0.08 to 2.92% and from 0.03 to 1.42%, respectively. The highest contents of these elements were recorded at the sites of historical Zn-Pb ore mining in the Repty and Stare Repty area, and in sediments of the watercourse running parallel to the Drama River upstream of the Dopływ spod Wilkowic Stream, which drains a meadow area.

The mercury content in most of the drainage basin sediments is close to the regional geochemical background level (0.06 mg/kg). Some sediments show an increased concentration of this element (0.20–0.36 mg/kg), probably due to anthropogenic factors.

Sediments of the upper part of the Drama River drainage basin (Rzepecki Rów Stream) contain remarkable concentrations of elements present in Zn-Pb ores: silver (2–12 mg/kg), cadmium (30–108 mg/kg), lead (1,240–13,880 mg/kg) and zinc (1,620–9,010 mg/kg). The high contents of iron (2–9%), manganese (1,700–2,490 mg/kg) and nickel (>20 mg/kg) in sediments of this part of the drainage basin is probably related to the presence and historical extraction of limonite iron ores (Nowak, 1927).

Pniowiec Stream and its catchment. The northeastern part of the map sheet area is covered with forests and belongs to the catchment of the Pniowiec Stream that flows into the Stoła River downstream of the Strzybnica sewage treatment plant. The drainage basin area is covered with glaciofluvial sands and gravels (Pl. 1) underlain by Triassic deposits (including Zn-Pb ore-bearing dolomites). The Zn-Pb ores were extracted in this region from the 16th century in several tens of shafts, and in eight mines in the 19th century (Filak, 2019). The erosion of soils polluted by the historical shallow mining of Zn-Pb ores in the upper course of the Pniowiec Stream is the main source of pollution in the catchment sediments.

Tabela 7
Table

Klasyfikacja gleb z głębokości 0,0–0,3 m ze względu na dopuszczalną zawartość pierwiastków potencjalnie toksycznych

Topsoil (0.0–0.3 m) classification according to the permissible content of potentially toxic elements

Pierwiastek Element	Wartości dopuszczalne stężeń w glebie (Rozporządzenie Ministra Środowiska z dnia 1 września 2016 r.) Permissible limit values in soil (Decree of the Polish Ministry of the Environment of 1th September 2016)			Liczba próbek /udział procentowy próbek w grupach użytkowania Number of samples/percentage of samples according to the pollution degree		
	Grupa I–III Group I–III	Grupa IV Group IV	A	Grupa I–III Group I–III	Grupa IV Group IV	A
	mg/kg					
As	<50	50–100	>100	1304 98,04%	13 0,98%	13 0,98%
Ba	<1000	1000–1500	>1500	1274 95,79%	41 3,08%	15 1,13%
Cr	<500	500–1000	>1000	1330 100%	–	–
Zn	<1000	1000–2000	>2000	1222 91,88%	62 4,66%	46 3,46%
Cd	<10	10–15	>15	1271 95,56%	29 2,18%	30 2,26%
Co	<100	100–200	>200	1330 100%	–	–
Cu	<300	300–600	>600	1316 98,95%	8 0,60%	6 0,45%
Ni	<300	300–500	>500	1330 100%	–	–
Pb	<500	500–600	>600	1174 88,27%	30 2,26%	126 9,47%
Hg	<10	10–30	>30	1330 100%	–	–

Grupa I–III – obszary zabudowy mieszkaniowej, użytków rolnych i lasów
Group I–III agricultural, forest and residential areas
Grupa IV – obszary przemysłowe
Group IV industrial areas
A – obszary o zawartości ponadnormatywnej
areas with oversized content

Sediments of the Pniowiec Stream (mainly between Tłuczykąt and Siwcowy Staw pond) and its numerous tributaries flowing from forest areas are also polluted with metals. Locally, they contain 20–55 mg/kg of cadmium, 150–360 mg/kg of lead, and 500–6,925 mg/kg of zinc.

In the upper part of the drainage basin area, most of the sediments are rich in aluminum (1.50–3.82%) and barium (300–1,133 mg/kg). They are also enriched in cobalt (20–115 mg/kg), iron (5.00–12.89%), manganese (3,500–22,110 mg/kg) and vanadium (40–140 mg/kg). The most likely source of most of these elements seems to be the drainage of dispersed waste from the mining of Zn-Pb ores and limonite. The source of barium can be the waste dispersed from the ZCH Tarnowskie Góry that produced barium chloride, barium nitrate and barium sulfate for several decades (Zakłady..., 2017). The concentration of metals in alluvial muds and peats of stream valleys is facilitated by the mineral composition of the sediments that are rich in organic matter, iron and manganese oxides and hydroxides, and clay minerals.

Stoła River and its catchment. The river begins its course in the Bobrowniki district. In the upper part of its drainage basin, Triassic ore-bearing dolomites that contain zinc and lead ores occur on the surface and under a thin cover of Quaternary sediments (Biernat, 1954; updated by Wilanowski, Lewandowski, 2016). The major source of pollution of the Stoła River sediments are the remains of tailings heaps left after the mining of Zn-Pb ores. The highest levels of metals are found in the upper reaches of the river, where ore tailings were dumped since the 16th century. The measured concentrations are as follows: silver 2–10 mg/kg, cadmium 3.1–237.7 mg/kg, lead 316–4,030 mg/kg, and zinc 680–6,010 mg/kg.

Sediments of the Stoła River catchment in the map sheet area show remarkable accumulations of chromium and copper up to 227 mg/kg and 736 mg/kg, respectively. The maximum contents of these metals are found downstream of the ZCH Tarnowskie Góry waste landfill, downstream of the Strzybnica area, as well as in sediments of the unnamed watercourse flowing into the Stoła River. Strong copper pollution of the topsoil layer (>160 mg/kg), found in the areas of the Tarnowskie Góry railway station and the ZCH waste landfill, indicates its anthropogenic origin (the use of copper sulfate in the production processes). The copper may also come from industrial wastewater discharges from the machinery industry located in the eastern part of Tarnowskie Góry (CHEMET – a manufacturer of pressure vessels and railway cisterns).

The sediments that are most heavily polluted with chromium and other metals were found in the unnamed watercourse draining the area of old landfills of the former Fryderyk silver and lead smelter, being later the factory of lead products and the iron foundry in Strzybnica. The Fryderyk smelter operated in 1786–1933, and since 1946, it has been a plant producing machinery and equipment for the mining industry (Huta Fryderyk..., Nowak *et al.*, 2014). The greatest pollution of sediments by metals was recorded in the upper reach of the watercourse that flows into the Stoła River just upstream of the Pniowiec Stream mouth. The following concentrations were recorded there: silver 3–5 mg/kg, cadmium 19.1–111.8 mg/kg, lead 400–1,551 mg/kg, and zinc 1,800–10,820 mg/kg. In these sediments, there are also significant concentrations of chromium (67–102 mg/kg), copper (219–482 mg/kg), iron (1.14–5.25%) and mercury (0.47–2.34 mg/kg).

Sediments of the upper reach of the Stoła River are significantly polluted with mercury. Its concentrations often exceed 1–2 mg/kg, and the maximum was 12.65 mg/kg. In the left-bank side of the drainage basin area, sediments of the streams and ditches are locally polluted at point sites by cadmium, lead and zinc.

SURFACE WATERS

Anthropogenic impact on water resources has the quantitative (change in water conditions), qualitative (water pollution, changes in chemistry) and topographical (transformation of watercourse channels and water body basins) aspects. In the last century, significant changes in the water quality were caused mainly by the increased supply of chemical pollutants and nutrients (Hajdukiewicz *et al.*, 2013; Gromiec, 2014).

The sources of threats to the quality of surface waters are surface runoff from industrial, agricultural and horticultural areas, leachate from landfills, and wastewater discharges. In the areas of mining of mineral deposits, one of the most important problems is the discharge of mine water to rivers and streams during and after extraction, causing chemical changes in the waters. As a consequence, the unfavourable changes lead to ecological effects such as disturbance of habitat conditions, disappearance of certain species, and reduction of biodiversity.

The tests of surface waters were performed to find out the content of selected chemical components, electrolytic conductivity, and pH. The content ranges of individual elements, components, and pH and EC of water in the study area, as well as the results of their calculated statistical parameters, are presented in Table 5. For comparison, the table contains the values of surface water quality indicators used in Poland, assuming the values determined for minor and medium-sized rivers on

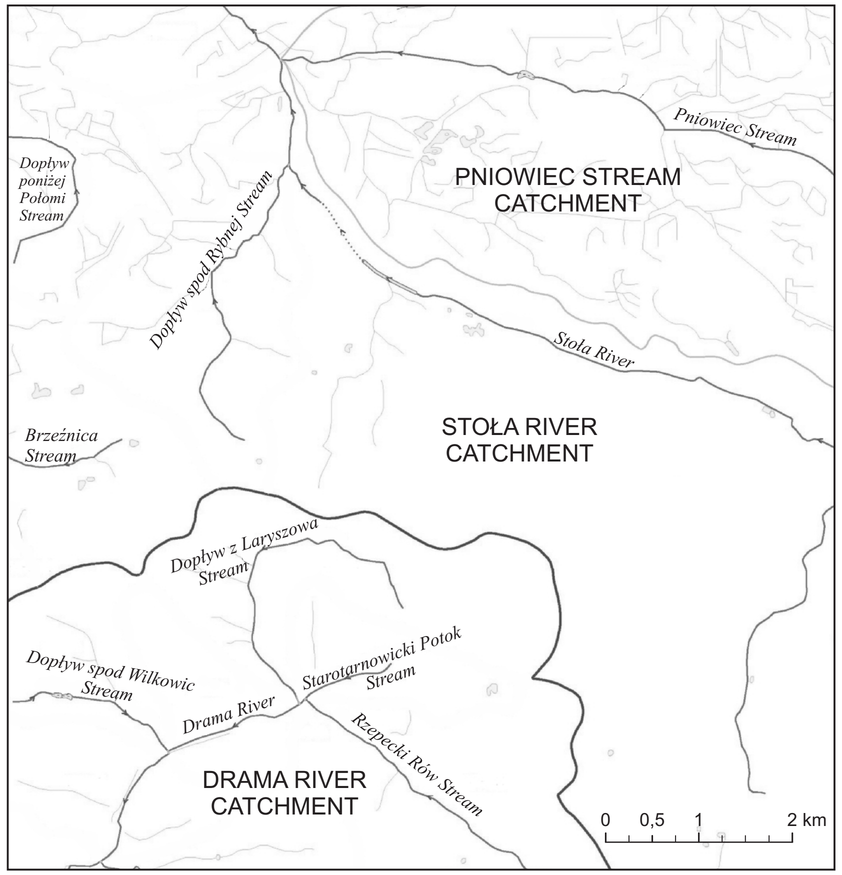


Fig. 3. Location of watercourses and stagnat water reservoirs and catchment areas (according to Mapa..., 2019)

carbonate bedrock (Rozporządzenie..., 2019). Additionally, the values of indicators for mineral waters and drinking waters according to the EU recommendations (EU Directive 1998/83/EC; EU Directive 2009/54/EC) are provided.

The pH value of waters in the map sheet area varies from 4.7 to 8.5, and does not meet the normative recommendations in some watercourses. The waters of pH <7 occur locally in the streams and ditches draining forest areas in the north of the map sheet. The water of the Drama River in the Repty region (between the Sylwester and Ewa shafts) stands out with a pH above 8. The average mineralization, expressed by the EC value (0.53 mS/cm), exceeds the limit value for water class II (Rozporządzenie..., 2019).

Drama River and its catchment. The waters of the Drama River catchment are of substandard class, although the river drains only agricultural land. The median contents of calcium, magnesium, phosphorus and sulfates exceed the limit for water quality class II (Tab. 5).

The electrolytic conductivity value of the drainage basin waters varies within the range of 0.38–1.70 mS/cm and the pH within the range of 6.3–8.3. Increased water mineralization (EC >1 mS/cm) was recorded in the Potok Starotarnowicki downstream of the sewage treatment plant and in the unnamed stream draining the Wilkowice area. In both cases, the water is probably loaded mainly by phosphorus (>1 mg/dm^3 in the Potok Starotarnowicki Stream and >3.5 mg/dm^3 in the stream flowing from Wilkowice). These waters are also rich in sodium (>100 mg/dm^3) and sulfates (>100 mg/dm^3). The source of these components is presumably surface runoff from fertilized fields, and discharges of municipal sewage that contains detergents.

The content of thallium and zinc proves the effect of water discharge from historical Zn-Pb ore mines on the water chemistry in the catchment. In most of the tested waters, the thallium and zinc contents are <0.05–0.09 µg/dm^3, and 0.004–0.058 mg/dm^3, respectively. After the inflow of waters from the Sztolnia Czarnego Pstrąga (Black Trout adit), the contents of these elements increase to 0.22–0.24 µg/dm^3 and 0.130–0.163 mg/dm^3, respectively. The calcium enrichment in water can be associated with the same source.

The waters of the Dopływ z Laryszowa Stream near the village of Laryszów are polluted locally. They contain cadmium 4.05 µg/dm^3, molybdenum 113,64 µg/dm^3, and zinc 0.422 mg/dm^3.

The content standards for other heavy metals are not exceeded. The only exception is the point anomaly of nickel content (228.3 mg/dm^3) in the Drama River waters downstream of the Adam shaft.

Pniowiec Stream and its catchment. The electrolytic conductivity value of the analyzed waters indicates their low salinity (the median EC is 0.41 mS/cm). The pH varies between 4.7 and 8.5. The waters of pH below 7, classified as substandard, occur mainly in minor streams of forest areas in the northeastern part of the map sheet area. The water acidification in the stream and its tributaries is related to the presence of soils in the drainage basin area, which are characterized by a very low pH and the elution of organic matter from the forest floor.

Due to the iron concentration value (median >0.3 mg/dm^3), most of the drainage basin waters are classified as substandard. The waters of ditches in the stream's drainage basin contain up to 10.46 mg/dm^3 of iron and up to 16.221 mg/dm^3 of manganese.

Some waters of the right-bank tributaries of the Pniowiec Stream are classified as substandard due to the aluminum content (400–4,035.3 µg/dm^3) related probably to the leaching of the element from sediments (alluvial muds) of the river valleys. The aluminum-rich waters also show a local increase in the contents of cadmium (up to 20.49 µg/dm^3), cobalt (up to 23.00 µg/dm^3), beryllium (up to 0.89 µg/dm^3), lead (up to 31.61 µg/dm^3), vanadium (up to 10 µg/dm^3) and zinc (up to 4.713 mg/dm^3).

The water of the watercourse flowing from Łąki Sosnowieckie to Tłuczykąt is loaded with boron that originates from drainage of the ZCH Tarnowskie Góry waste landfill (0.77–1.22 mg/dm^3 in the upper course).

The thallium content (up to 0.53 µg/dm^3) does not exceed the limit for water quality classes I and II. The results of analyses for other elements show little variation in their concentrations and are not indicative of pollution.

Stoła River and its catchment. The water chemistry in the drainage basin area is affected mainly by leachate from the Chemical Plant ZCH Tarnowskie Góry landfill and by sewage discharges from the Leśna treatment plant in Strzybnica and the Central Sewage Treatment Plant in Tarnowskie Góry. Most of the Stoła River waters are characterized by electrolytic conductivity value above 1 mS/cm (up to 1.44 mS/cm), which proves significant mineralization. In the waters of both its right-bank and left-bank tributaries, the EC value is much lower. It is commonly in the range of 0.20–0.50 mS/cm. The pH of the drainage basin waters is 4.8–8.3. Substandard waters (pH <7.3) were found in 30% of the drainage basin water samples.

In the northwestern forest-covered part of the catchment, high aluminum concentration in the waters of minor watercourses (locally >1,000 µg/dm^3) is noticeable, while in the Stoła River waters, the common records for aluminum are 10–30 µg/dm^3.

In the upper reach of the Stoła River (especially between the sewage treatment plant in Sowice to Kolonia Piaseczna Mała), the water is loaded with several elements. These include boron (12–16 mg/dm^3), barium (0.708–1.338 mg/dm^3), manganese (0.717–0.925 mg/dm^3) and strontium (0.809–0.998 mg/dm^3). Due to the contents of boron and barium, most of these waters are classified as substandard.

In the waters of the Stoła River, the concentration of phosphorus is commonly in the range of 1–2 mg/dm^3, with a maximum of 4.56 mg/dm^3. Much greater amounts of this element are found in its tributaries (up to 6.24 mg/dm^3). What draws attention in the Stoła River waters is the molybdenum concentration exceeding 20 µg/dm^3 in its upper course and reaching 10–15 µg/dm^3 in the middle and lower reaches. Molybdenum may be sourced here from discharges of industrial wastewater. In the waters of the Stoła River tributaries in the western part of the drainage basin, the natural concentration of this element usually does not exceed 0.05 µg/dm^3. In the upper reaches of the river, the waters are also polluted by nickel reaching a level of 115.5–606.9 µg/dm^3. Most of the waters of the Stoła River drainage basin are characterized by high concentrations of calcium (up to 116.1 mg/dm^3), magnesium (up to 115.6 mg/dm^3) and sulfates (up to 710 mg/dm^3). Due to the accumulation of iron, part of the drainage basin waters is classified as substandard. At several locations, its concentration exceeds 1 mg/dm^3, reaching a maximum of 6.71 mg/dm^3 in the waters of the unnamed stream flowing from Kopanina. At several locations in the drainage basin area, water pollution with cadmium was noted to be at a level of several µg/dm^3.

CONCLUSIONS

1. The sources of anthropogenic pollution of natural environment are as follows: leachate from tailings heaps, mine water discharges due to historical mining and processing of zinc-lead ores, leachate from the Chemical Plant ZCH Tarnowskie Góry waste landfill, from metal plants and galvanizing plants, industrial and municipal sewage discharges, and surface runoff from agricultural land, urban areas, roads and railroads.

2. The grain-size composition of the soils is clearly related to the lithology of the parent material; sandy soils predominate throughout the map sheet area.

3. The diversity of soil pH is related largely to the land use. Highly acidic and acidic pH is characteristic of forest soils in the northern part of the map sheet area. In the remaining area, neutral soils are predominant; however, alkaline soils prevail in urban areas. The alkalization is caused by fallout of dusts originating mainly from coal combustion for energy, heating and industry purposes.

4. The distribution of the content of most of the elements (cobalt, chromium, copper, iron, magnesium, manganese, nickel, phosphorus, strontium, titanium and vanadium) in soils, which are sourced mainly from the parent rocks, does not differ from the geochemical background level of the Silesian-Cracow region. The soils are approximately twice enriched in barium, and almost three times enriched in lead.

5. The chemical composition of soils in the southeastern part of the study area and in the Stoła River valley is remarkably transformed by anthropogenic factors. Anthropogenic anomalies of silver, arsenic and cadmium were found in both topsoil and subsoil in the areas of mining and processing of Zn-Pb ore deposits, around the sites of historical silver smelting from galena, in the area of the former Strzybnica zinc smelter, near heaps and dumps left after this activity, and along ore transportation routes.

6. The soils, sediments and waters are polluted by barium and copper due to the presence of compounds of these elements, which come from the Chemical Plant ZCH Tarnowskie Góry landfill.

7. Silver, arsenic, cadmium, lead and zinc in the sediments come from the drainage of mine waste heaps of zinc and lead ores and dispersed sites of silver smelting from the ores. The enrichment with iron and manganese is probably associated with the historical exploitation of limonite.

8. Most of the tested waters are alkaline and characterized by mineralization exceeding the limit value for waters of quality class II. Discharges of water from historical Zn-Pb ore mines slightly pollute the water of some streams by cadmium, molybdenum, thallium and zinc. The water of the watercourses draining the Chemical Plant ZCH Tarnowskie Góry waste landfill area is polluted by barium, boron, copper, sulfates and strontium. The water of the watercourses that drain sewage treatment plant areas is polluted with phosphorus.

REFERENCES

ACOSTA J.A., MARTINEZ-MARTINEZ S., ZORNOZA R., CARMONA D.M., KABAS S., 2011 – Multivariate statistical and GIS-based approach to evaluate heavy metals behaviour in mine sites for future reclamation. *J. Geochem. Explor*., **109**: 8–17.

ADAMO P., ARIENZO M., BIANCO M.R., TERRIBILE F., VIOLANTE P., 2002 – Heavy metal contamination of the soils used for stocking raw materials in the former ILVA iron-steel industrial plant of Bagnoli (southern Italy). *Sci. Total Environ*., **295**: 7–34.

ALBANESE S., BREWARD N., 2011 – Sources of Anthropogenicc Contaminants in the Urban Environment. *W*: Mapping the Chemical Environment of Urban Areas (red. Ch. Johnson, A. Demetriades i in.): 116–127. Wiley-Blackwell, Chichester.

BAUEREK A., BEBEK M., FRĄCZEK R., PAW K., KASPERKIEWICZ W., 2017 – Zmienność składu chemicznego kwaśnych wód spływu powierzchniowego z czynnej hałdy odpadów górniczych reprezentujących osady krakowskiej serii piaskowcowej Górnośląskiego Zagłębia Węglowego. *Prz. Geol*., **65**: 450–458.

BEDNAREK R., DZIADOWIEC H., POKOJSKA U., PRUSINKIEWICZ Z., 2004 – Badania ekologiczno-gleboznawcze. PWN, Warszawa.

BIERNAT S., 1954; reambulacja WILANOWSKI S., LEWANDOWSKI J., 2016 – Szczegółowa Mapa Geologiczna Polski 1:50 000, ark. Bytom. Państw. Inst. Geol., Warszawa.

BOJAKOWSKA I., SOKOŁOWSKA G., 2001 – Rtęć w kopalinach wydobywanych w Polsce jako potencjalne źródło zanieczyszczenia środowiska. *Biul. Państw. Inst. Geol*., **394**: 5–54.

BOJAKOWSKA I., GLIWICZ T., MAŁECKA K., 2006 – Wyniki geochemicznych badań osadów wodnych Polski w latach 2003–2005. Biblioteka Monitoringu Środowiska, Warszawa.

BN-78/9180-11, 1978 – Gleby i utwory mineralne. Podział na frakcje i grupy granulometryczne. Norma branżowa.

BUŁA Z., KOTAS A. (red.), 1994 – Atlas geologiczny GZW w skali 1:100 000 cz. III. Mapa geologiczno-strukturalna utworów karbonu produktywnego. Wyd. Państw. Inst. Geol., Warszawa.

BYSTRZANOWSKI Ł., ZASTRZEŻYŃSKA J., JARUSZOWIEC M., 2015 – Program ochrony środowiska dla powiatu tarnogórskiego na lata 2016–2020 z perspektywą do roku 2024. https://www.bip.tarnogorski.pl/?catid=72&parcat=11&t=more&grupa=15e3a689177b2e (dostęp 12.01.2021).

BZOWSKI Z., DAWIDOWSKI A., 2007 – Bor, bar i stront w zanieczyszczonych glebach i odpadach zdeponowanych w rejonie Tarnowskich Gór a obecność tych pierwiastków w wodzie Małej Panwi. Uniwersytet Zielonogórski. *Zeszyty Nauk*., **133**: 52–61.

CABAŁA J., 1996 – Koncentracje pierwiastków śladowych w rudach Zn-Pb i możliwość przechodzenia ich do odpadów. *Pr. Nauk. Główn. Inst. Górn., ser. Konferencje*, **13**: 17–32.

CABAŁA J., 2009 – Metale ciężkie w środowisku glebowym olkuskiego rejonu eksploatacji rud Zn-Pb. Wyd. Uniwersytetu Śląskiego, Katowice.

CABAŁA J., TEPER L., 2007 – Metalliferous constituents of rhizosphere soils contaminated by Zn-Pb mining in southern Poland. *Water, Air and Soil Pollution*, **178**: 351–362.
CÁNOVAS C.R., PEIFFER S., MACÍAS F., OLÍAS M., NIETO J.M., 2015 – Geochemical processes in a highly acidic pit lake of the Iberian Pyrite Belt (SW Spain). *Chem. Geol*., **395**: 144–153.
CAPPUYNS V., SWENNEN R., VANDAMME A., NICLAES M., 2005 – Environmental impact of the former Pb–Zn mining and smelting in East Belgium. *J. Geochem. Expl*., **88**: 6–9.
CEMPIEL E., CZAJKOWSKA A., NOWIŃSKA K., POZZI M., 2014 – Przejawy antropopresji w zlewni rzeki Bytomki. Wyd. Politechniki Śląskiej, Gliwice.
CISZEWSKI D., 1997 – Source of pollution as a factor controlling distribution of heavy metals in bottom sediments of Chechło River (south Poland). *Environ. Geol*., **29**: 50–57.
CISZEWSKI D., 2002 – Zapis działalności przemysłowej w osadach fluwialnych. *W*: Zapis działalności człowieka w środowisku przyrodniczym (red. P. Szwarczewski, E. Smolska), t. 1: 23–28. Bogucki Wyd. Naukowe, Warszawa-Łomża.
CISZEWSKI D., 2005 – Osady pozakorytowe Odry jako archiwum historii zanieczyszczenia rzeki metalami ciężkimi. *W*: Współczesna ewolucja rzeźby Polski (red. A. Kotarba, K. Krzemień, J. Święchowicz): 60–67. VII Zjazd Geomorfologów Polskich. IGiGP UJ, Kraków.
DEGENHARDT O., 1870 – Der Oberschlesian-Polnische-Bergdistrict mit Hinweglassung des Diluviums. Karte von Oberschlesien 1 : 100 000. Verlag der Landkarten handlung von J.H. Neumann, Berlin.
EU DIRECTIVE 1998/83/EC Drinking Water.
EU DIRECTIVE 2009/54/EC Natural Mineral Water.
FILAK M., 2019 – Pniowiec. *Montes Tarnovicensis*, **97**. http://www.montes.pl/montes_/index.php?option=com_content&view=article&id=1057:pniowiec&catid=91:montes-tarnovicensis-nr-97&Itemid=2385 (dostęp 16.07.2020).
FRIESE K., 2002 – Depth distribution of heavy metals in lake sediments from lignite mine pit lakes of Lusatia (Germany). *Stud. Quatern*., **21**: 197–205.
FUGE R., PEARCE F.M., PEARCE N.J.G., PERKINS W.T., 1993 – Geochemistry of Cd in the secondary environment near abandoned metalliferous mines, Wales. *App. Geochem., Supplement*, **2**: 29–35.
GROMIEC M., 2014 – Zagrożenia związane z jakością wody: zanieczyszczenia i propozycje rozwiązań. *Gospodarka Wodna*, **10**: 377–383.
GEOGNOSTISCHE KARTE von Ober-Schlesien, Section Gleiwitz, Blatt № 8.
GRUSZECKA-KOSOWSKA A., BARAN A., WDOWIN M., MAZUR-KAJTA K., CZECH T., 2020 – The contents of the potentially harmful elements in the arable soils of southern Poland, with the assessment of ecological and health risks: A case study. *Environmental Geochemistry and Health*, **42**: 419–442.
GRZECHNIK Z., 1978 – Historia dotychczasowych poszukiwań i eksploatacji. *W*: Poszukiwanie rud cynku i ołowiu na obszarze śląsko-krakowskim. *Pr. Inst. Geol*., **83**: 23–39.
HAJDUKIEWICZ H., WYŻGA B., ZAWIEJSKA J., AMIROWICZ A., OGLĘCKI P., RADECKI-PAWLIK A., 2013 – Stan środowiska rzek południowej Polski – znaczenie środowiskowe, degradacja i możliwości rewitalizacji rzek wielonurtowych (red. B. Wyżga). Instytut Ochrony Przyrody PAN, Kraków.
HARNISCHMACHER S., 2007 – Anthropogenic impacts in the Ruhr district (Germany): a contribution to anthropogeomorphology in a former mining region. *Geogr. Fis. Dinam. Quat*., **30**: 185–192.
HINWOOD A.L., HEYWORTH J., TANNER H., MCCULLOUGH C., 2012 – Recreational use of acidic pit lakes – Human Health Considerations for Post Closure Planning. *J. Water Res. Protect*., **4***:* 1061–1070.
HŁAWICZKA S., 2008 – Rtęć w środowisku atmosferycznym. Wyd. Instytutu Podstaw Inżynierii Środowiska PAN, Zabrze.
HUTA FRYDERYK. https://pl.wikipedia.org/wiki/Huta_Fryderyk
IBRAGIMOW A., GŁOSIŃSKA G., SIEPAK M., WALNA B., 2010 – Wstępne badania zanieczyszczenia metalami ciężkimi osadów równin zalewowych Lubuskiego Przełomu Odry. *Pr. Stud. Geogr*., **44**: 233–247.
JENDRUŚ R., 2015 – Opinia górniczo-geologiczna dla ul. Klonowej i Kasztanowej w Tarnowskich Górach. Geoprojekt „Śląsk", Katowice.
JURECZKA J., DOPITA M., GAŁKA M., KRIEGER W., KWARCIŃSKI J., MARTINEC P., 2005 – Atlas geologiczno-złożowy polskiej i czeskiej części Górnośląskiego Zagłębia Węglowego. Państw. Inst. Geol., Warszawa.
KABATA-PENDIAS A., MUKHERJEE A., 2007 – Trace Elements from Soil to Human. Springer-Verlag, Berlin Heidelberg.
KABATA-PENDIAS A., SZTEKE B., 2015 – Trace Elements in Abiotic and Biotic Environments. Taylor and Francis Group, CRC Press, Boca Raton.
KALEMBASA S., GODLEWSKA A., WYSOKIŃSKI A., 2008 – Skład chemiczny popiołów z węgla brunatnego i kamiennego w aspekcie ich rolniczego zagospodarowania. *Rocz. Gleb*., **59**: 93–97.
KIERSNOWSKI H., 1991 – Litostratygrafia permu północno-wschodniego obrzeżenia Górnośląskiego Zagłębia Węglowego – nowa propozycja. *Prz. Geol*., **39**: 198–203.
KLASYFIKACJA uziarnienia gleb i utworów mineralnych, 2008. Polskie Towarzystwo Gleboznawcze. http://ssa.ptg.sggw.pl/artykul/2635/particle-size-distribution-and-textural-classes-of-soils-and-mineral-materials-classification-of-pol (dostęp 15.07.2020).
KONDRACKI J., 2009 – Geografia regionalna Polski. PWN, Warszawa.
KOTLICKI S., 1995 – Badania nad litostratygrafią triasu Górnego Śląska: 123–140. Arch. Państw. Inst. Geol., Sosnowiec.
KOŚCIELNY H., ROSENBAUM S., 2013 – Tarnowskie Góry. Przyroda. Urząd Miejski w Tarnowskich Górach.
KOZIEŁ M., ZGŁOBICKI W., 2010 – Metale ciężkie w aluwiach Wieprza na obszarze Nadwieprzańskiego Parku Krajobrazowego. *Ochr. Środ. Zas. Nat*., **43**: 26–37.
LIS J., PASIECZNA A., 1995a – Atlas geochemiczny Polski w skali 1 : 2 500 000. Wyd. Państw. Inst. Geol., Warszawa.
LIS J., PASIECZNA A., 1995b – Atlas geochemiczny Górnego Śląska w skali 1 : 200 000. Wyd. Państw. Inst. Geol., Warszawa.
LIS J., PASIECZNA A., 1997 – Anomalie geochemiczne Pb-Zn-Cd w glebach na Górnym Śląsku. *Prz. Geol*., **2**: 182–190.
LIS J., PASIECZNA A., 1999 – Szczegółowa mapa geochemiczna Górnego Śląska w skali 1 : 25 000, ark. Sławków. Państw. Inst. Geol., Warszawa.
MAJER E., 2004 – Rekultywacja terenów zdegradowanych przez przemysł chemiczny na przykładzie Tarnowskich Gór. Seminarium EU GeoEnvNet Geoinżynieria środowiska – transfer doświadczeń i dyrektyw UE do nowo przyjętych państw. http://kg.sggw.pl/konf/art_en/17.pdf (dostęp 23.02.2021).
MAJORCZYK R., 1985 – Historia górnictwa kruszcowego w rejonie Bytomia. ZUP Piekary Śląskie.
MAJORCZYK R., 1986 – Historia górnictwa kruszcowego w rejonie bytomskim od połowy XIX wieku. Część III. *Rudy Metale*, **31**: 442–446.
MAPA Hydrograficzna Polski w skali 1 : 50 000, ark. Bytom, 2019. KZGW, Warszawa.
MIDAS (System Gospodarki i Ochrony Bogactw Naturalnych Państwowego Instytutu Geologicznego-PIB). http://geoportal.pgi.gov.pl/midas-web (dostęp 25.01.2021).
MIGASZEWSKI Z.M., GAŁUSZKA A., 2016 – Geochemia środowiska. PWN, Warszawa.
MIKOŁAJKÓW J., SADURSKI A. (red.), 2017 – Informator PSH. Główne zbiorniki wód podziemnych w Polsce. Państw. Inst. Geol., Warszawa.
MOCEK A., DRZYMAŁA S., MASZNER P., 2000 – Geneza, analiza i klasyfikacja gleb. Wyd. Akademia Rolnicza, Poznań.
MOLENDA D., 1960 – Górnictwo kruszców. *W*: Zarys dziejów górnictwa na ziemiach polskich, t. 1: 120–162. Wyd. Górniczo-Hutnicze, Katowice.
MOLENDA D., 1972 – Kopalnie rud ołowiu na terenie złóż śląsko-krakowskich od XVI do XVIII wieku. Z dziejów postępu technicznego eksploatacji kruszców: 25–31. Wyd. Ossolineum, Wrocław.
NAVARRO M.C., PÉREZ-SIRVENT C., MARTÍNEZ-SÁNCHEZ M.J., VIDAL J., MARIMÓN J., 2006 – Lead, cadmium and arsenic bioavailability in the abandoned mine site of Cabezo Rajao (Murcia, SE Spain). *Chemosphere*, **63**: 484–489.
NOWAK J., 1927 – Kronika miasta i powiatu Tarnowskie Góry. Księgarnia Polska Jana Nowaka w Tarnowskich Górach.
NOWAK A., BIERNACKA-NOWAK D., SIKORA K., NOWICKI M., PŁATEK M., 2014 – Studium uwarunkowań i kierunków zagospodarowania przestrzennego na obszarze całej gminy Tarnowskie Góry. Pracownia Urbanistyki i Architektury, Tarnowskie Góry.
PASIECZNA A., 2003 – Atlas zanieczyszczeń gleb miejskich w Polsce. Państw. Inst. Geol., Warszawa.
PASIECZNA A., 2018 – Wpływ historycznej eksploatacji rud cynkowo-ołowiowych oraz hutnictwa żelaza i cynku na zanieczyszczenie gleb w centralnej części Górnośląskiego Okręgu Przemysłowego. *Biul. Państw. Inst. Geol*., **473**: 49–66.
PAULO A., STRZELSKA-SMAKOWSKA B., 2000 – Rudy metali nieżelaznych i szlachetnych. Wyd. AGH, Kraków.
PAWLAK Z., FILAK M., 2017 – Tarnowskie Góry/UNESCO. Wyd. Stowarzyszenie Miłośników Ziemi Tarnogórskiej, Tarnowskie Góry.
PIERNIKARCZYK J., 1984 – Sztolnia Czarnego Pstrąga w Tarnowskich Górach. Wyd. „Sport i turystyka", Warszawa.
PIERNIKARCZYK J., 1926 – Tarnowskie Góry. Kolebka przemysłu śląskiego. Nakładem Górnośląskiego Związku Przemysłowców Górniczo-Hutniczych, Katowice.
PIERNIKARCZYK J., 1933 – Historia Górnictwa i hutnictwa na Górnym Śląsku 2. Nakładem Śląskiego Związku Akademickiego, Katowice.
PN-R-04033, 1998 – Gleby i utwory mineralne. Podział na frakcje i grupy granulometryczne. Polski Komitet Normalizacyjny, Warszawa.
PRADELA A., SOLARSKI M., 2013 – Rozwój górnictwa rud cynku i ołowiu w bytomsko-tarnogórskim rejonie złożowym od końca XVIII wieku do czasów współczesnych. *W*: Z badań nad wpływem antropopresji na środowisko (red. R. Machowski, M.A. Rzętała), t. 14: 43–50. Wyd. UŚ, Katowice.
PROJEKT Programu Ochrony Środowiska dla Powiatu Tarnogórskiego na lata 2016–2020 z perspektywą do roku 2024. Powiat Tarnowskie Góry. http://docplayer.pl/64929608-Projekt-programu-ochrony-srodowiska-dla-powiatu-tarnogorskiego-na-lata-z-perspektywa-do-roku-2024.html (dostęp 22.09.2020).
PROGRAM Ochrony Środowiska Gminy Tarnowskie Góry do roku 2021, 2016 – Urząd Miasta Piekary Tarnowskie Góry. https://bip.tarnowskiegory.pl/Article/get/id,81538.html (dostęp 12.10.2020).
RAZOWSKA-JAWOREK L., BRODZIŃSKI I., 2016 – Bytom. *W*: Wody podziemne miast Polski: 3–18. Państw. Inst. Geol., Warszawa.
ROZPORZĄDZENIE Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z dnia 11 października 2019 r. w sprawie klasyfikacji stanu jednolitych części wód powierzchniowych, a także środowiskowych norm jakości dla substancji priorytetowych. DzU poz. 2149.
ROZPORZĄDZENIE Ministra Środowiska z dnia 1 września 2016 r. w sprawie sposobu prowadzenia oceny zanieczyszczenia powierzchni ziemi. DzU poz. 1395.
RYŻAK M., BARTMIŃSKI P., BIEGANOWSKI A., 2009 – Metody wyznaczania rozkładu granulometrycznego gleb mineralnych. *Acta Agrophysica*, **175**: 1–79.

RZECZYCKI T., 2008 – Tarnowskie Góry: zarośnięta kopalnia pod ochroną. http://nettg.pl/news/74437/tarnowskie-gory-zarosnieta-kopalnia-pod-ochrona (dostęp 22.09.2020).
SIEDLECKA A., 1964 – Osady permu na północno-wschodnim obrzeżeniu Zagłębia Górnośląskiego. *Rocz. Pol. Tow. Geol.*, **34**: 309–394.
SOJKA M., SIEPAK M., GNOJSKA E., 2013 – Ocena zawartości metali ciężkich w osadach dennych wstępnej części zbiornika retencyjnego Stare Miasto na rzece Powie. *Ochrona Środowiska*, **15**: 1916–1928.
STAN Środowiska w Województwie Śląskim, 2020 – GIOŚ, Katowice. http://www.gios.gov.pl/images/dokumenty/pms/raporty/stan_srodowiska_2020_slaskie.pdf (dostęp 14.12.2020).
STATYSTYKA Zakładów Górniczych i Hutniczych na polskim Górnym Śląsku za 1927 rok, 1928. Górnośląski Związek Przemysłowców Górniczo-Hutniczych, Z.Z. w Katowicach. http://www.sbc.org.pl/Content/29280/iii4249-1927.pdf (dostęp 10.10.2020).
STOJIČ N., PUCAREVIČ M., STOJIČ G., 2017 – Railway transportation as a source of soil pollution. *Transportation Research Part D Transport an Environment*, **57**: 124–129. DOI: 10.1016/j.trd.2017.09.024.
SWENNEN R., VAN DER SLUYS J., 2002 – Anthropogenic impact on sediment composition and geochemistry in vertical overbank profiles of river alluvium from Belgium and Luxembourg. *J. Geochem. Explor.*, **75**: 93–105.
SZADKOWSKA Z., GWÓŹDŹ M., 2015 – Program ochrony środowiska dla gminy Radzionków do roku 2020. Radzionków. http://bip.radzionkow.pl/?a=17667 (dostęp 12.09.2020).
SZUFLICKI M., MALON A., TYMIŃSKI M. (red.), 2020 – Bilans Zasobów Złóż Kopalin w Polsce wg stanu na 31 XII 2019 r. Państw. Inst. Geol., Warszawa.
SZUWARZYŃSKI M., 1996 – Ore bodies in the Silesian-Cracow ore district, Poland. *Pr. Państw. Inst. Geol*., **154**: 9–24.
WIECZOREK E., 2009 – Bytom i okolice. Przewodnik turystyczny. Wyd. Urząd Miejski w Bytomiu.
WIŁKOMIRSKI B., SUDNIK-WÓJCIKOWSKA B., GALERA H., WIERZBICKA M., 2011 – Railway transportation as a serious source of organic and inorganic pollution. *Water Air and Soil Pollution*, **218** (1–4): 333–345.
WONG C.S.C., LI X., THORNTON I., 2006 – Urban environmental geochemistry of trace metals. *Environmental Pollution*, **142**: 1–16.
ZAKŁADY Chemiczne Tarnowskie Góry: ekologiczna bomba, 2017. https://www.chemiaibiznes.com.pl/aktualnosc/zaklady-chemiczne-tarnowskie-gory-ekologiczna-bomba (dostęp 13.05.2020).
ZGŁOBICKI W., 2008 – Geochemiczny zapis działalności człowieka w osadach stokowych i rzecznych. Wyd. UMCS, Lublin.
ŻERO E., 1968 – Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50 000, ark. Bytom (910). Wyd. Inst. Geol., Warszawa.