INTRODUCTION

Geochemical mapping of Poland (Lis, Pasieczna, 1995a, b) shows that the most polluted soils, aqueous sediments and surface water occur in the Silesian-Cracow region. In the area of the discovered anomalies of heavy metals, mapping works on "Detailed geochemical map of Upper Silesia (SMGGŚ)", scale 1:25 000 started in 1996 with a pilot project of the Sławków Map Sheet (Lis, Pasieczna, 1999). The publication has been prepared in the form of atlases for successive map sheets. It provides information useful for environmental management and making decisions by local authorities.

Geochemical mapping carried out in the Imielin Map Sheet M-34-63-C-b area is the continuation of detailed cartographic survey that has been conducted in the Silesian-Cracow region by the Polish Geological Institute–National Research Institute since 1996. The project was ordered by the Ministry of the Environment and financed by the National Fund for Environmental Protection and Water Management. The purpose of the study is to assess environment pollution in the area of long-lasting hard coal and rock raw materials mining accompanied by developing other industry sectors.

The Imielin Map Sheet area covers part of the Bieruń-Lędziny poviat, southern districts of Jaworzno and Mysłowice towns and part of the Chełmek commune. The land management of the area is of rural-urban character with a significant contribution of industrial and commercial facilities. Industrial facilities are distributed throughout the whole map sheet area. Low block development predominates in urban areas. Part of the map sheet area is covered with forests. Arable fields and meadows with flora and fauna habitats account for a considerable proportion of the area. The characteristic feature of the landscape is the man-made Dziećkowice reservoir of drinking water, which also plays recreational functions as well as a number of fish ponds.

The main economy activity of the area is hard coal mining of the KWK Ziemowit and KWK Piast mines located in the Upper Silesian Coal Basin (USCB) and quarrying of dolomites and limestones. An important role is played by the water production plant (Zakład Produkcji Wody) in Imielin and metal processing and automotive and building industries. Since the early 1990s, the mining industry has diminished due to industrial restructuring. Instead, processing industry, small businesses, and retail and service activities have developed. The economic use of post-mining waste has also improved.

The results of geochemical researches, presented in a cartographic form with a comprehensive explanatory text and data tables, show the current qualities of soils, aqueous sediments and surface water in relation to the natural regional background and the regulation guidelines. The information provided in this publication can be useful in preparing physiogeographic reports, land use planning, assessing local plans, making decisions concerning environmental constraints, giving water-legal permits, assessing groundwater hazards and discharging duties imposed upon district governors by the Environmental Protection Law, i.e. conducting regular soil quality tests within the framework of the state monitoring system.

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

A number of specialists participated in the preparation of this report:

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- **A. Biel, A. Pasieczna, A. Dusza-Dobek** – construction of geochemical maps;
- **A. Paulo** – characteristics of the map area, geology and mineral deposits;
- **A. Paulo, A. Biel** – human impact;
- **A. Pasieczna, A. Biel** – interpretation of results.

CHARACTERISTICS OF THE MAP AREA

Geographical and administrative setting. Most of the area of Imielin Map Sheet M-34-63-C-b is situated in the Silesian Voivodeship and covers part of the Bieruń-Lędziny poviat (part of the communes of Imielin, Bieruń, Lędziny and the Chełm Śląski) and the southern districts of Jaworzno and Mysłowice towns. A small area in the south-eastern part of the map sheet is included in the Chełmek commune of the Oświęcim poviat in the Małopolskie Voivodeship. The Przemsza River is the border between the Voivodeships.

According to the physiogeographic subdivision of Poland, the study area belongs to the Pagóry Jaworznickie hills, which are a part of the Silesian Upland (Kondracki, 2000).

Relief and geomorphology. The Pagóry Jaworznickie hills are a belt of tectonic horsts composed of Triassic deposits overlying Carboniferous rocks. The relief is strongly related to the tectonic structures of the basement.

The horst hills are composed of Triassic limestones and dolomites and extend from the Hołdunów (up to 278 m a.s.l) by Imielin through Pasieczki and Jazd (up to 310.1 m a.s.l.), between Chełm Śląski and Chełmek (up to 284.6 m a.s.l.) and around the Ściernie (up to 260 m a.s.l.). Individual hills separate vast, locally wet valleys filled with Miocene clays, glacial tills and glaciofluvial sandy deposits. The valleys developed in the area of tectonic grabens crossing the central part of the map sheet area. The meridional valley is called the Reden-Imielin Graben, whereas the longitudinal valley is the continuation of the Chrzanów-Dąb Graben (Krysowska, 1967). The Przemsza and Potok Goławiecki valleys extending in the southern part of the map sheet lie at the elevation of approximately 235 m a.s.l.

The contemporary relief is strongly modified and altered by industrial plants and infrastructure.

Open casts of the active Imielin dolomite mine are located in the hilly area near the northern boundary of the map sheet. In Lędziny (close to the western boundary), there is a post-mining dump of the KWK Ziemowit hard coal mine, currently under land reclamation, covering the area of 35.4 ha, and some tailings ponds (Plates 1 and 2). The KWK Piast hard coal mine facilities are situated in the southern part of the map area. Part of the mine's wastes has been used for land reclamation purposes, forming the belt of individual heights in the recreation park at the site of the former Paciorkowce ponds in Bieruń beyond the southern boundary of the map sheet area (Myczkowski, 2003).

Hydrographic changes, including river engineering and wetland drainage works, are common in this area. Post-mining lakes and wetland depressions that were formed as a result of underground coal mining-induced subsidence occur in forests and uncultivated areas.

Above underground working pits of coal mines, broad mining subsidence troughs (depressions) and so-called discontinuous deformations like fractures, cracks and scarps (Chwastek et al., 1990) developed. The Kudrowiec pond is located in such a depression.

The most characteristic and the largest water reservoir in the map sheet area (and the whole Silesian Upland) is the Dziećkowice reservoir (Jezioro Imielińskie Lake) covering the area of about 7.3 km^2. The reservoir supplies drinking water for the Silesian agglomeration and plays recreational functions. The reservoir was formed in a working pit of filling sands in the Przemsza River valley. Its construction entailed the necessity of moving the Przemsza River bed towards the east. The reservoir was completed in 1976 within the framework of the water supply system construction for the Huta Katowice smelting works, with the ultimate target of being used as the water supply system for the Katowice agglomeration (Bok et al., 2004). The reservoir is situated outside the Przemsza River bed. It is supplied by water transported from the Skawa and Soła rivers system through the pumps station in Broszkowice near Oświęcim, which operates only during increased flows. The outflow of water from the reservoir is done by the use of pumps. The reservoir's total capacity is 52.8 million m^3, and the water is of high quality.

The reservoir infrastructure includes hydrotechnical systems e.g. a frontal dam, two side dams, water intake for the Upper Silesian Water Supply Enterprise (Górnośląskie Przedsiębiorstwo Wodociągów) and for the ArcelorMittal iron smelter, pipeline outfalls of the Broszkowice pumps station, the Chełmek pumps station and pipeline outfalls of a water purification station.

The Dziećkowice reservoir serves three water producers (including Zakład Produkcji Wody in Imielin) within the operations of the Water Supply Service Enterprise (Przedsiębiorstwo Usług Wodociągowych) in Dąbrowa Górnicza, which is part the Upper Silesian water management system (Przedsiębiorstwo..., 2010)

A smaller drinking water reservoir that was formed at the site of the former settling pond of the KWK Piast hard coal mine is situated to the West of the Imielinka Stream valley in Chełm Śląski.

There are also important water reservoirs of the Pacwowe Stawy Ponds in the Mąkowiec Stream valley.

The map area is situated in the Przemsza River drainage basin - a part of the Vistula River drainage basin. The Przemsza River has two right-bank tributaries: Imielinka and Potok Rothera streams. The second longest stream of the area is the Potok Goławiecki (with an engineered riverbed) flowing directly into the Vistula River. The Mąkowiec Stream is a left bank tributary of the Potok Goławiecki. Small watercourses conveying water into the Rów Kosztowski and Przyrwa streams drain the northern part of the map area.

The north-eastern part of the map sheet belongs to the Triassic fissured-karst major groundwater reservoir (GZWP 452 Chrzanów; Kleczkowski, 1990; Strzemińska, Formowicz, 2002).

Land use. The sheet area is rural-urban with a significant contribution of industrial facilities and transportation routes. Non-built-up areas cover 80% of the map sheet, urban areas account for 13%, rural areas cover 4%, and industrial areas – 3% (Plates 2 and 3).

Much of the area is barren land (32%). Arable fields occupy 25% of the area, grassland makes 11%, and forests 23% (Plate 3). The remaining area includes lawns, urban parks, gardens, water reservoirs, roads and train tracks.

Economy. The surveyed area is a part of the Upper Silesian Industrial Region (Górnośląski Okręg Przemysłowy – GOP). The main industrial centres are Lędziny, Imielin, Chełm Śląski and Ściernie – a district of the Bieruń Nowy. The basic economy sector of the area is hard coal mining. In Lędziny, there is a number of main shafts, including one extraction shaft of the KWK Ziemowit hard coal mine (operating since 1952), mine's repair and manufacturing services and numerous coal trade and freight forwarder companies. A large logistics and warehouse complex is under construction. The main shafts and mine office buildings of the KWK Piast coal mine are located in Ściernie.

The most economically important enterprises in Imielin include the following: dolomite and limestone quarries and processing facilities, water production company (Zakład Produkcji Wody), retail and service businesses of the metallurgy sector (producing metal sheets, aluminium foil, pipes and alloy castings) as well as ironwork, carpentry, motor car and building services.

The largest enterprise of Chełm Śląski is a ventilator manufacturer. The Bata footwear company (Poland's largest footwear company) has operated in Chełmek since 1931.

GEOLOGY AND MINERAL DEPOSITS

Geological structure of the area is well known due to mining operations that have been conducted over many years. The area is situated in the eastern part of the Upper Silesian Coal Basin (USCB). The basement of the USCB is composed of crystalline rocks overlain by Cambrian through Devonian sedimentary formations (Buła, Kotas, 1994; Buła, Żaba, 2005). These, in turn, are overlain by Carboniferous, Triassic and Cenozoic deposits bounded by unconformities.

The oldest well-explored rock formation is the Upper **Carboniferous** series composed of sandstones, siltstones, clay shales and coal seams. In the area of economic interest (to the depth of 1000 m), there are the Westphalian Łaziska Beds of the Kraków Sandstone Series and the underlying siltstone series of the Orzesze Beds (Krysowska, 1967). The Łaziska Beds, about 680 m in thickness, are represented by arkosic and calcareous sandstones, and conglomerates with rare clay shale interbeds and relatively thick (2 to 4.7 m) coal seams. They are exposed at the surface near Hołdunów, composing hill which is a tectonic horst rising above the Quaternary deposits (Plate 1).

The siltstone-shale Orzesze Beds contain sandstone interbeds, siderite concretions and several tens of thin coal seams (0.9 to 2.8 m thick).

The Mesozoic structural stage is represented by Lower and Middle **Triassic** sedimentary formations composing hills near Hołdunów, Imielin, Chełm Śląski, Chełmek and Ściernie. The Lower Triassic includes a 30 m thick package of Roethian marine dolomites and limestones underlain by a few metres thick Rotliegend continental sands and clays. These deposits are outcropped only in the area between Chełm Śląski and the Przemsza River valley.

Middle Triassic deposits are represented by the 30 m thick Gogolin Beds (platy and conglomeratic limestones with marl interbeds), overlain by 30–40 m thick ore-bearing dolomites and Diplopora dolomites variably thick as a result of erosional reduction of the top series. The Gogolin Beds limestones have been extracted in Chełmek and Ściernie for a long time and used as fluxing agents and raw materials for production of overburnt lime (Krysowska, 1967). Extensive outcrops of ore-bearing and Diplopora dolomites stretch from Imielin through Pasieczki to the northern boundary of the map sheet (Plate 1). These rocks are currently extracted in the Imielin quarries and used in the crushed stone aggregate sector.

Neogene deposits are represented by Miocene marine marly clays and sands (Krysowska 1967) distributed in topographic lows throughout the whole map area. Their thickness is variable and related to relief variations of the top of Carboniferous and Triassic formations. Natural exposures of these deposits occur between Smardzowice and Goławiec and in Zagórze near the Przemsza River valley.

The **Quaternary** is represented by Pleistocene glacial and glaciofluvial deposits and Holocene fluvial muds and peats. Aeolian dune sands occur sporadically near Gorzów close to the south-eastern boundary of the map area. Thin Odranian Glaciation tills are exposed in several patches. Pleistocene glaciofluvial sands and gravels form an extensive cover. Holocene sands, muds and gravels compose accumulation terraces in the valleys of the Przemsza and Potok Goławiecki rivers and of smaller streams. In the Przemsza ice-marginal valley, the sand thickness was several metres thick, but it was reduced as a result of mining activity in the 20th century.

Mineral deposits. Multi-seam **hard coal** deposits occur throughout the whole map sheet area. Coal is extracted from the Łaziska Beds and underlying Orzesze Beds. The coal seams of Łaziska Beds are water-containing and strongly contaminated by sulphur. The coal seams of the Orzesze Beds are thin. They locally contain high-ash coals and are rarely qualified for extraction.

The KWK Ziemowit and KWK Piast coal mines extract 2–5 m thick coal seams of the Lędziny I mining area (63.58 km^2) that extends from Katowice and Mysłowice in the North, to Lędziny, Imielin and Chełm Śląski in the South. The coal comes from the Łaziska Beds.

The KWK Piast (formerly Bieruń) coal mine was built in 1972–75. It operates in mining area covering 48.31 km^2. Its small part is located between Bieruń Stary and Chełm Śląski.

The Triassic carbonate formations contain **limestone** and **dolomite** deposits quarried by the Imielin mine in the Imielin-Rek economic deposit located near the northern boundary of the map area. The thickness of the dolomites and limestones ranges from 7 to 31.2 m and from 2.8 to 24.4 m, respectively. The exposed Gogolin Beds, containing the average of 43.8–50.1% CaO, 2.2–3.2% MgO, 0.7–1.1% Fe_2O_3 and 0.7–4.3% Al_2O_3 (Szuwarzyńska, 1997), are the main source of calcium, magnesium, iron and aluminium to the soils developed on their outcrops.

The extracted raw stone material is used for production of stone aggregate for the building industry and road construction. On the northern side of the quarry, there is a small pile of overburden rocks used for engineering works.

Miocene **clays** were used for brick production. Quaternary **sands** were used by the local building sector and as filling material in coal mines.

HUMAN IMPACT

Natural environment of the region has been altered mainly due to long-lasting hard coal mining activity accompanied by changes in the hydrographic system, discharges of saline and low-level radioactive waters, dumping of mining wastes, post-mining subsidence and loss of stability of buildings above unsupported underground excavations. Extraction of raw stone materials and their mass transport has had a smaller effect on the environment.

Atmospheric air. The atmospheric air is polluted mainly by emissions from industrial combustion of fuels (coke and coal dusts, aromatic and aliphatic hydrocarbons, sulphur dioxide, nitrogen dioxide, carbon oxide and dioxide), road transportation (hydrocarbons, carbon oxide, lead compounds), industrial processes (hydrocarbons, fluorine, hydrogen sulphide) and from mine shafts and landfills. Long-distance emission of pollutants from the Upper Silesian Industrial Region (especially from Bieruń Stary, Tychy and Rybnik) and from the Ostrava-Karvina Region in the Czech Republic (through the Moravian Gate) is another source of the air contamination.

The largest volume of air pollution originates from power and heating plants operating at the KWK Piast and KWK Ziemowit coal mines, heating plants of other industrial companies, non-ferrous metals warehouse (Skład Metali Nieżelaznych), water production plant (Zakład Produkcji Wody) in Imielin, and ventilator manufacturer (Fabryka Wentylatorów) in Chełm Śląski. They emit carbon oxide and dioxide, sulphur dioxide, nitrogen oxides and PM 10 dust.(Program…, 2003).

Single point pollution sources include furnaces of individual houses that contribute to the emission of PM 10 dust from hard coal and coke combustion, especially during the heating season. Dust precipitation values fall within the limits prescribed by the Ministry of the Environment (Program…, 2003).

Local contamination by benzo(α)pyrene and elemental carbon results from technological processes of the asphalt roofing manufacturer situated in Bieruń Nowy beyond the southern boundary of the map area.

The amount of air pollution originating from motor engine exhausts depends on traffic intensity. The air in the areas stretching along the A4 motorway and the Eastern Bypass of the Upper Silesian Industrial Region are especially exposed to contamination. High pollution values are also observed along access roads of the KWK Ziemowit and KWK Piast coal mines, where coal lorry traffic is very heavy.

Surface water and groundwater. The water is contaminated mainly due to hard coal mining activity that causes both drainage of several multiaquifer formations through mine excavations and discharge of saline mining water. The runoff is impeded and the hydrographic network changes in post-mining subsidence areas. The water of the Przemsza River and Potok Goławiecki Stream show the highest contamination values in the Silesian Voivodeship (Stan..., 2008).

Carboniferous deposits of the Upper Silesian Coal Basin exhibit remarkable hydrochemical zonation. There is the general trend of increasing groundwater mineralisation with depth according to the sequence HCO_3–SO_4–Cl (Różkowski, ed., 2004). The KWK Piast and KWK Ziemowit coal mines pump out brines only (Kubicka..., 2009). Mining water is first discharged into settling ponds, and after water clarification using coagulants, it is conveyed to the watercourses. The KWK Piast and KWK Ziemowit coal mines are among those discharging the greatest amounts of mining water in the USCB, which is radioactive and contains the highest concentrations of chlorides and sulphates (> 42 g/dm^3). The average mining water discharges from the KWK Piast and KWK Ziemowit coal mines in 2007 were 23 750 m^3/day and 41 760 m^3/day, and the average salt discharges were 1475 and 818 t/day, respectively.

To reduce the negative effect of the discharges on the environment, the coal mines implement special systems of mining water discharges into the rivers. In case of low water levels, mining water is conveyed to the recently closed Czeczott coal mine (outside the map area). Important water purification operations take place directly in the subsurface and include radium removal. Technology of radioactive water purification is based on removal of radium using sorbents (barite and barium chloride), and the purification process leads to considerable reduction of the amount of the isotopes that are introduced into the rivers (Jabłońska, Sobik-Szołtysek, 2007; Olkuski, Stala-Szlugaj, 2009; Smoliński, 2006).

Eluates from mine wastes dumped and weathered on the surface are a significant source of surface water pollution. Mineralised pore water is removed from the wastes, and pyrite oxidation leads to the release of sulphates and sulphuric acid. In an acidic environment, heavy metals are mobilized and even aluminosilicates are decomposited and release of aluminium occur. Eluates from barren rock piles located near mine shafts contain excessive concentrations of sulphates, chlorides and some metals (Program…, 2003).

The environment is also degraded due to the improper waste and sewage management. Some industrial companies have own sewage treatment plants, but many others discharge sewage into the municipal sewage system that serves almost a half of the residents in this region, and the degree of sewage purification is insufficient (Program…, 2003). There is a new sewage treatment plant in the Imielin commune, built in 2008. The Chełm Śląski sewage treatment plant purifies only 20% of wastewater generated in the commune.

The other sources of contamination of surface water is runoff from towns, roads, car parking lots and petrol stations, as well as chemical substances used in agriculture.

Soils. Degradation of soils is expressed by reduction in humus content, change in soil acidity, moisture and structure, and loss of nutrients. In consequence, the soil becomes less fertile. The important factors affecting the soil conditions include emissions of dust, industrial gases and motor fumes, dumping of wastes and improper agriculture. Harmful heavy metals, nitrogen and organophosphate compounds, chlorinated hydrocarbons, and other substances are introduced into the soils due to the use of mineral fertilizers, sludge precipitates and pesticides. Chemical contamination by heavy metals is mainly due to activity of industry, vehicle repair services and transportation. Local contamination of the soils is caused by dumping of outdated pesticides and fluorescent lamps, mining wastes and natural weathering of ore-bearing rocks.

According to the monitoring conducted by the Katowice Institute for Ecology of Industrial Areas (Instytut Ekologii Terenów Uprzemysłowionych), most of the soils from the western and northern parts of the Bieruń-Lędziny poviat represent soils of class A, allowing plant cultivation without restraints. About 15% of the soils contain increased contents of heavy metals. High acidity of soils was observed in the river valleys (Program…, 2003).

MATERIALS AND METHODS

The 2007–2010 researches included studying published and archival materials, selecting sampling sites in topographic maps at the scale of 1:10,000, collecting samples, coordinate surveying at sampling sites, chemical analyses of samples, setting up field and laboratory databases, preparing vector topographic sheet, statistical calculations, constructing geochemical maps and a geological map, and finally interpretation of results. The sequence of investigations is shown in Figure 1.

FIELD WORKS

Soil samples were collected at a regular grid of 250x250 m (16 samples per 1 km^2). The total number of soil sampling sites was 1329 (Plate 2). At every site, two samples were collected from two depths: 0.0–0.3 (topsoil) and 0.8–1.0 m (subsoil). If the parent rock was found shallower in the soil profile, the subsoil sample was collected at a smaller depth. Soil samples (ca. 500 g) were collected using a 60 mm hand probe, put in linen bags labelled with numbers, and pre-dried on wooden pallets at a field storage site.

Samples of aqueous sediments and surface water were collected form rivers, streams, melioration ditches, canals, settling ponds, pools and ponds. The distance between watercourse sampling sites was about 250 m. 500 g sediment samples (of possibly the finest fraction) were taken from water reservoir shores using a ladle. They were subsequently placed in 500-ml plastic containers labelled with numbers.

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

All the sampling sites were marked at topographic maps at the scale of 1:10 000 and numbered. Locations of the sampling sites were defined with GPS, using a device equipped with an external antenna and a computer which can record not only coordinates but also additional information (pH and EC of water samples, data on land development and land use as type of soil and aqueous sediment). The coordinates were taken with the accuracy of ±2 – 10 m. The coordinates of soil sampling sites were put into the memory of the GPS equipment, before going out in the field, and the sites were subsequently found using the satellite positioning system. For database safety reasons, all the field data were also noted on special sampling cards (Fig. 2).

LABORATORY WORKS

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

Aqueous sediment samples were air-dried and then sieved through a 0.2 mm nylon sieve. The <0.2 mm fraction was divided into two portions: one of them was used for chemical analysis and the other was archived (Fig. 1).

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

Chemical analyses were carried out at the Central Chemical Laboratory of the Polish Geological Institute–National Research Institute in Warsaw.

Soil and aqueous sediment samples were digested in aqua regia (1 g of sample to final volume of 50 ml) for 1 hour at the temperature of 95°C in the aluminium heating block thermostat.

Contents of Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Mg, Mn, Ni, P, Pb, S, Sr, Ti, V and Zn in the soil and aqueous sediment samples were determined by an inductively coupled plasma atomic emission spectrometry (ICP-AES) method. Mercury content was measured using a cold vapour atomic absorption spectrometry (CV-AAS) method. Soil pH (H_2O) was measured using a pH-meter. Organic carbon content was measured using a coulometric method. Determination of B, Ba, Ca, Cr, Fe, K, Mg, Mn, Na, P, SiO_2, SO_4, Sr, Ti and Zn in surface waters was performed by an ICP-AES method. Contents of Ag, Al, As, Cd, Cl, Co, Cu, Li, Mo, Ni, Pb, Rb, Sb, Tl and U were analysed using an ICP-MS method. The applied analytical methods and the detection limits of measured elements are shown in Table 1.

The control of the determinations was performed through analysis of duplicate samples (about 3% of all samples), analysis of reference materials with certified content of elements studied (2.5% of all samples) and analysis of laboratory control samples confirming correct instrument calibration (10% of all samples). 'Reagent blank samples' and 'preparation blank samples' were used. Purity of reagents and vessels was controlled with 'reagent blank samples'. 'Blank samples' (*sea sand extra pure Merck*) were used to monitor for possible contamination introduced during the sample preparation procedure.

For the solid samples, analytical precision is below 25%. For the surface water samples, analytical precision is about 15–25% (depending on the element's concentration).

Grain size analyses of topsoil (0.0–0.3 m) samples were carried out at the Hydrogeology and Engineering Geology Laboratory of the Polish Geological Institute–National Research Institute in Warsaw, using a laser particle size analyzer. Advantages of the laser technique include the following: small sample volume (<1 g), quick measurement and high determination accuracy with regard to some grain sizes (Dębicki *et al.*, 2002).

The comparisons of the results of grain-size analyses obtained using a sieve-sedimentation method (according to the international classification of FAO and USDA) and the laser technique show significant differences in the proportions of individual fractions (Kasza, 1992; Issmer, 2000). Thus, direct use of laser method results does not allow soil classification according to pedological criteria. However, the data are very useful for interpretation of geochemical analyses.

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

DATABASES AND GEOCHEMICAL MAP CONSTRUCTION

Base topographic map. The 1:25 000 scale topographic base map was constructed using the most up-to-date *1992* coordinate system topographic map at the scale of 1:50 000, Katowice Map Sheet M-34-63-A (vector map VMap L2). The topographic map contains the following vector information layers: relief, hydrography (including dividing into rivers, streams, ditches and stagnant water reservoirs), road communication network (with road classes indicated), railway network, land development (including classification into rural, urban and industrial development), forests, industrial areas (industrial objects, mine shafts, mine excavations, mine dumps and tailing ponds).

Geological map. Geological map was constructed on the basis of Detailed Geological Map of Poland, 1:50 000, Katowice Map Sheet (Biernat, Krysowska, 1956). Individual elements of the geological map were digitized to create their vector images which were subsequently combined with the topographic base, producing the geological map at the scale of 1:25 000 (Plate 1).

Database management. Separate databases were prepared for: topsoil (0.0–0.3 m), subsoil (0.8–1.0 m), aqueous sediments and surface water.

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

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

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

Map construction. The following maps were produced for the Katowice Sheet (Plates 2–63): land development, land use, contents of organic carbon and grain-size of topsoil (sand, silt and clay fractions); acidity of topsoil and 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 topsoil, subsoil and in aqueous sediments; acidity, specific electrical conductivity and contents of Ag, Al, As, B, Ba, Ca, Cd, Cl, Co, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, Sb, SiO_2, SO_4, Sr, Ti, Tl, U, Zn in surface water and topsoil classification indicating appropriate soil use.

Land development, land use and topsoil classification indicating appropriate soil use are presented as dot maps (Plates 2, 3 and 63).

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

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

The geochemical maps of soils were constructed using the analytical dataset created for the Katowice Sheet and the datasets of 1:25 000 scale neighbouring sheets. Thus any disagreements at the sheet borders were avoided. After interpolation from mono-element maps the Katowice Sheet was extracted and combined with the topographic base map.

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

While constructing the map of soil classification (Plate 63), indicating appropriate soil use, the results of geochemical analyses were referred to the permissible levels of metals, defined in the Regulation of the Ministry of the Environment (Rozporządzenie...,2002), according to the recommendation that 'soil or land is considered polluted if the concentration of at least one substance exceeds the permissible limit value'.

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

For publication purposes, the geochemical maps were constructed by combining the maps into pairs: the topsoil map is presented together with the aqueous sediment map, and the subsoil map is shown with the surface water map. This method of presentation provides the possibility of direct comparison of geochemical images of various media. Taking into account the comfort of potential users, the maps (with a bar scale shown) have been printed out in a slightly smaller format (A3). This operation did not cause omitting any important details of the maps. The whole report or its individual plotter-printed maps are available for those who are interested in 1:25 000 scale maps.

RESULTS

SOILS

In addition to natural soil-forming factors, the soil quality is also influenced by anthropogenic factors resulting in changes in the soil profile and physicochemical properties. Soil degradation processes occur mainly in industrial areas, dump sites, urban areas and near transportation routes.

Parent rocks of soils are represented by lithologically diversified deposits of various age (Plate 1). Various soils types developed on these rocks, reflecting chemical composition of the basement.

The most common soil types are *Podzols* developed on Quaternary glaciofluvial sandy deposits. Tills are the parent rocks of *Cambisols*. *Rendzinas* occur in the areas of limestones and dolomites of the Imielin and Garb Lędziński elevations. *Anthrosols* occupy small areas (Program..., 2003). River valleys are covered by muds, whereas topographic lows are filled with *Histosols*.

Grain size. One of the factors affecting content of chemical elements in soils is grain size. For soils rich in the clay fraction (<0.02 mm) and silt fraction (0.1–0.02 mm), the permissible concentrations of metals are commonly higher while preparing recommendations for soil use (Kabata-Pendias *et al.*, 1995). These soils contain high concentrations of elements and their migration ability within the soil profile is low..

The following grain size groups have been distinguished within the topsoil of the study area: 1.0–0.1 mm, 0.1–0.02 mm and <0.02 mm, according to the Polish Standard BN-78/9180-11 (1997) recommended by the Polish Society of Soil Science (Polskie Towarzystwo Gleboznawcze).

Grain size analyses show a remarkable relationship between the parent rock lithology and the grain size of soil. The most common are sandy soils developed on Pleistocene glaciofluvial sands and gravels, and on glacial sandy tills (Plates 1 and 4). These soils contain over 75% of the 1.0–0.1 mm fraction. Patches of soils containing above 90% of the sand fraction (Plate 4) occur in the north-western and south-eastern parts of the map area (in forests).

The proportion of the silt fraction (0.1–0.02 mm) is variable. The smallest proportion of this fraction (<10%) is observed in the soils developed on glaciofluvial sandy deposits (Plate 5). In most of the map area, the dominant proportion of this fraction in the soils is 10–15%, and the values >15% are observed in the soils developed on Triassic carbonate-marly deposits.

The clay fraction (<0.02 mm) accounts for 5–10% of the total soil volume (Plate 6). The proportions of 10–15% were recorded only in the soils developed on Triassic deposits and in those patchily occurring in the river valleys. The highest proportion of the clay fraction (>15%) is observed in anthropogenic soils near the barren rock dump and settling ponds of the KWK Ziemowit coal mine.

Acidity of the soils is constrained primarily by lithology of parent rocks, which is best marked in the subsoil at the depth of 0.8–1.0 m.

The topsoil is dominated by acidic soils (Plate 7). Very acidic soils (pH<5) occur in forests (Plates 2 and 7). Neutral and alkaline soils cover approximately 30% of the map area, mainly in the outcrops of Triassic carbonates and in urban-industrial areas.

The comparison of average acidity values of the topsoil between areas of different land use (Table 2) shows a clear relationship between alkalinity and dustfall from fuel combustion and industrial processes. Acidic soils (pH 5.0–6.8) occur mainly in grassland, pastures, uncultivated land and stream valleys. Neutral soils are observed in agriculture areas and idle lands.

In the subsoil (0.8–1.0 m), the proportions of acidic, neutral and alkaline soils are 45%, 34% and 21%, respectively. The dominant neutral and alkaline soils are located mostly in the central and eastern part of the map area. In urban-industrial areas, the soil alkalinity is related to both the occurrence of Triassic carbonate bedrock and emission of industrial dust fall rich in calcium and magnesium compounds. Chemical composition of the parent rocks is of higher significance, as evidenced by larger alkaline areas within the subsoil horizon (depth 0.8–1.0 m).

Strongly alkaline soils (pH ≥ 8) occur around the northern shores of the Dziećkowice reservoir (near a former glass smelter), which can be associated both with the effect of reactions between smelter wastes and eluates from contemporary furnace waste landfill and with the use of building materials for shore reinforcement.

Geochemistry. The average contents of all chemical elements in the topsoil (expressed in medians) are around or below the geochemical background values for the Silesian-Cracow region (Table 2).

Spatial distribution of elements in the soils is determined mainly by the bedrock lithology. The soils that developed on Pleistocene glaciofluvial sands and gravels contain less aluminium, barium, calcium, cobalt, chromium, iron, magnesium, manganese, nickel, phosphorus, strontium, titanium and vanadium than the soils genetically related to clay and carbonate deposits.

Enrichment of the soils in aluminium (>0.40%), clearly visible at the depth of 0.8–1.0 m, is observed in the areas: Imielin–Pasieczki–Podkamieniec in the North of the map sheet, in the Hołdunów–Smardzowice–Lędziny in the West, and in the Chełm Śląski and Chełmek. In these areas, the soils contain increased amounts of iron (>0.50%), nickel (>5 mg/kg), titanium (>100 mg/kg) and vanadium (>10 mg/kg).

The most characteristic association of chemical elements related to carbonate deposits includes calcium, magnesium, manganese and strontium. The soils abundant in these elements occur in the Imielin–Pasieczki–Podkamieniec area, near Hołdunów, on hills on both sides of the Przemsza River valley as well as near Ściernie and the KWK Piast coal mine close to the southern boundary of the map sheet. The calcium and magnesium contents exceed 0.5% in these areas, locally reaching a few percent. Abundance of the elements is favourable to the soil environment causing increase of acidity. It also favours binding of heavy metals. In the soils rich in calcium and magnesium, the manganese and strontium contents exceed 400 mg/kg and 20 mg/kg, respectively.

The topsoil is not rich in organic carbon. In most of the area, its content is 0.70–3,00%. The low amounts are observed in the soils of the central part of the map area, developed on Triassic carbonates and Quaternary tills, whereas the high contents (>6%) were recorded in the soils of forests and near coal mine facilities.

The average phosphorus content in the topsoil is 0.030%, with the most common values of 0.015−0.060%. The sulphur concentration rarely exceeds 0.080%. Near tailings piles and mine shafts, the sulphur content is locally >0.160%. The phosphorus distribution in the topsoil clearly depends on the soil use. The arable field and grassland soils contain more phosphorus (average 0.030%) than the forest soils (0.015%). The content of sulphur and phosphorus decreases with depth.

Enrichment of the soils in some elements (barium, zinc, cadmium, lead, mercury and copper), marked particularly in the topsoil, is caused by anthropogenic factors. The soils that are the most chemically altered due to industrial activity occur in the Przemsza River valley, near dolomite quarries in Imielin, and near mine shafts and settling ponds.

The soil contamination by barium is caused by both human impact and geogenic factors, as evidenced by the comparison of images of its spatial distribution in both the topsoil and subsoil. In the subsoil, the enrichment in barium (>60 mg/kg) is observed only in the areas of Triassic outcrops and in the seepage spring area of the Potok Goławiecki Stream. In the topsoil, the area of barium content of >60 mg/kg is more extensive. The content exceeds even 120 mg/kg in the strongly contaminated soils of the Przemsza River valley and in the industrial areas of the south-western part of the map sheet.

The considerable contamination by metals is observed in the alluvial topsoils in the Przemsza River valley. The wetland and boggy terrain is an area of organic matter accumulation easily binding mineral components. The metals originate from water and suspended matter transported from all over the drainage basin. They are retained in the soils during periodic floods. The concentrations of cadmium, mercury, lead and zinc in this area exceed 4 mg/kg, 0.10 mg/kg, 50 mg/kg and 250 mg/kg, respectively. There is also a local enrichment in copper.

The soils enrichment in cadmium (>4 mg/kg), lead (>50 mg/kg) and zinc (>250 mg/kg), and additionally in iron (>1%) and nickel (>20 mg/kg) in the subsoil, is observed in the northern part of the map area composed of Triassic carbonate-marly deposits. The metals are probably sourced from dispersed ore mineralisation in the parent rocks.

The 0.0–0.3 m depth soils near the KWK Ziemowit coal mine and tailings piles are contaminated by metals and sulphur, but the anomalies are not extensive although some of them continue at the depth of 0.8–1.0 m. The following concentration values were noted in these areas: chromium – up to 172 mg/kg, copper – up to 170 mg/kg, nickel – up to 190 mg/kg, lead – up to 1200 mg/kg, titanium – up to 2300 mg/kg, vanadium – up to 85 mg/kg, zinc – up to 1200 mg/kg, sulphur – up to 0.276%.

Local enrichment of the topsoil in mercury (>0.10 mg/kg) was observed in the Przemsza River valley, in Chełm Śląski and near some industrial objects and residential areas. A strong single point mercury anomaly (with the maximum of 1.92 in the topsoil and 7.82 mg/kg at the depth of 0.8–1.0 m) was found South of Kopciowice. The presumed source of mercury is the pesticide graveyard. A Miocene clays deposit (category C_2, 27 ha in size) has been documented in this area (Szuwarzyńska, 1997). It appears a promising subject of interest for ceramic industry investors, but the contamination of the clays by mercury can be a serious hazard to the environment in the case of clays extraction. Due to toxicity of mercury, the anomaly requires more detailed examination.

Along the railway line and near the abandoned mine shaft of the KWK Ziemowit hard coal mine, West of Cisowiec, the soils are enriched in metals (copper, mercury, nickel and lead), probably as a result of metallurgy industry activity. The presence of sulphur and organic carbon (>12%) indicates that coal was stored at this site.

Because cadmium, lead and zinc can easily cumulate and be harmful to plants and microorganisms inhabiting the soil environment, the amount of area contaminated by these metals to different extents was estimated for the map sheet (Table 6). In most of the map sheet area (93.78%), the topsoils contain below 4 mg/kg of cadmium. The lead content <100 mg/kg is observed in 92.17% of the soils, whereas the zinc <500 mg/kg in 95.72% of the soils. The soils strongly polluted by cadmium (>16 mg/kg), lead (>500 mg/kg) and zinc (>2500 mg/kg) occupy only 0.16–0.24% of the total map area in the topsoil and 0.17% at the depth of 0.8–1.0 m.

The heavy metal contamination of soils is a problem for the local authorities and should be discussed with respect to the appropriate land use. To fit the geochemical data to the local authorities' needs the topsoils of the Imielin Sheet were classified applying current guideline values (Table 7) established by the Polish Ministry of the Environment (Rozporządzenie…,2002). The guideline values are based on the average of particular elements in soils for Poland as a whole and also on the assessment if the content of a particular element may have negative influence on the ecosystem or on human health. Guideline values are applied for three-level scale: A (protected areas), B (agricultural, forest and residential areas) and C (industrial areas).

An estimation of the degree of contamination by metals was carried out for the topsoil, classifying them with respect to soil use into the groups A, B and C based on permissible limit values (Rozporządzenie…, 2002). The total classification was calculated using the rule that the sample is classified to a particular soil use group if the content of at least one element exceeds the permissible limit value. With respect to contents of metals, 35.30% of the soils were included into group A. Group B is represented by 51.37% of the samples, whereas 13.33% of the samples were classified into group C (Plate 63). The map shows the recommended land use according to the guidelines provided in Rozporządzenie... (2002). Much of the soils are currently improperly used and require monitoring and local reclamation. The contents of metals in the soils of some forest, agricultural, grassland and garden areas are so high that the land should be used for industrial purposes only.

The only soils that meet requirements of multi-purpose use are those categorized into classes A and B. Class C soils occur in the Przemsza River valley, near quarries in Imielin, in Ściernie, near the KWK Ziemowit coal mine facilities and in some urban areas. Lead, cadmium, zinc and barium are the most common pollutant elements of the soils (Table 7).

AQUEOUS SEDIMENTS

Aqueous sediments were sampled from rivers, streams, canals, lakes, settling ponds, fish and non-fish ponds and from the Dziećkowice artificial reservoir.

Przemsza River. The sediments were collected at the downstream river section, where pollution from the whole vast drainage basin accumulate. The Przemsza River, rising in Sosnowiec city from the joint of the Czarna and Biała Przemsza Rivers drains the most industrialised and urbanised part of the Upper Silesian Industrial Region. There are numerous landfills of hard coal post-mining wastes and iron and steel smelters, discharging metals, oxides of iron, aluminium, calcium and magnesium, sulphur, industrial oils, cyanides and many other substances in sewage. In the upstream of the Przemsza River and its tributaries, there are a few hundred of sewage discharge points (including municipal sewage from the largest cities of the region). The influx of pollution from so many sources results in strong chemical degradation of the sediments, as evidenced by increased average concentrations of many elements, especially metals, as compared with the regional geochemical background values (Table 4).