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MONITORING OF ENVIRONMENTAL BURDENS IN SLOVAKIA – PART I

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Preface

Environmental burdens represent a long-term and serious problem for the quality of the environment of the Slovak Republic. In the past, they arose mainly from improper handling of dangerous substances, which directly or indirectly entered the individual components of the environment and contaminated (or still contaminate) them for a long time. The environmental burdens represent a wide range of areas contaminated by industrial, military, mining, transport and agricultural activities, but also by improper waste management. Environmental burdens can pose a potential threat to human beings and the environment (especially groundwater, rock environment or air pollution).

Since 2012, the State Geological Institute of Dionýz Štúr has been carrying out projects related to the monitoring of contaminated sites, perceived as environmental burdens, currently in more than 300 sites. The aim of the projects is to design and implement the monitoring programme for environmental burdens in Slovakia, to identify leakage of pollutants into the environment (especially into groundwater and surface water) and their extent and to assess the trends in concentrations of pollutants. The monitoring activities carried out are in line with the EU Water Framework Directive and its "Daughter" Directive on Groundwater Protection. Monitoring of environmental burdens fulfils the programme objectives of the Government of the Slovak Republic, which are defined in the document "State programme of remediation of environmental burdens for the years 2010 – 2015" and the same document for the years 2016 – 2021. The list of monitored environmental burdens (at SGIDŠ) is attached to this issue of the journal.

Due to the topic extent the articles are submitted in two issues of the journal **in the year 2019** – four articles in the issue 1/2019 and four articles in the issue 2/2019.

Geological works carried out in the framework of the environmental burdens monitoring focus mainly in characterizing the rock environment, including tracking of processes taking place in the area of the environmental burden, monitoring the character and properties of pollutants, as well as obtaining information on the nature of the burden itself. The character and properties of the rock environment are usually monitored on the basis of petrographic description of rock material, hydrogeological properties, engineering eological characteristics and geochemical properties including isotope composition. **In the first article** attention is paid to the main principles and methods applied in the environmental burdens monitoring in Slovakia.

When investigating the old environmental burdens, the methods of applied geophysics are advantageously used for their efficiency and speed of screening in the area of objects of interest. The results of these works provide information about the studied area indirectly – based on the analysis of various (geo)physical fields and physical parameters of the rock environment. Outputs of interpretation of geophysical measurements enable to optimize localization of other activities (sampling and drilling works, etc.) and thus can significantly contribute to the solution of the problem of the environmental burdens. However, this issue cannot be more generalized and each geophysical measurement at a particular site/object should be modified according to specific field, structural-geological, hydrogeological, engineering geological, etc., conditions. Use of the applied geophysics in the environmental burdens monitoring is dealt with **the second paper**.

Assessment of the negative effects of the environmental burdens is enabled also by using of remote sensing methods. The remote sensing is applicable particularly by comparing images from several time periods focused in the territory of the environmental burden and its immediate surroundings, especially in the area of the interaction zone. Changes can be identified by direct and indirect spatial symptoms on vegetation, soil, snow cover, as well as on the condition of roads, buildings, technology, etc. Application of remote sensing in monitoring of the environmental burdens is summarized **in the third article**.

The monitored sites represent a wide range of economic activities that have been carried out in the past. "Waste management facilities" (121 sites) are the largest economic activities in the evaluated sites, followed by "industrial production" (78 sites) and "warehousing and distribution of goods" (26 sites). Waste management facilities are predominantly municipal waste landfills (62 sites), waste storage facilities and treatment facilities (19 sites), industrial waste landfills (18 sites) and tailings ponds (14 sites). Industrial production is mostly represented by engineering (25 sites), chemicals (15 sites) and metal processing and treatment (8 sites). The chemical composition of water is often changed around environmental burdens and is shifting from standard types, such as $Ca\text{-}HCO_3$ and $Ca\text{-}Mg\text{-}HCO_3$, to types with a higher proportion of substances of secondary origin (Na^+, Cl^-, SO_4^{2-}). Pollution is also often manifested by an increase in the total dissolved solids and high conductivity values. Due to contamination from landfills as well as some other types of contamination, frequent occurrence of increased contents of boron, Cl^-, NH_4^+, SO_4^{2-} and increased conductivity values are observed. Concerning the organic compounds, chlorinated hydrocarbons, especially cis- 1,2-dichloroethene, dichloromethane, tetrachloroethene, trichloroethene, chloroethene, appear to be the most problematic at the sites of concern. Due to the inclusion of the mining sites in monitoring, elevated concentrations of some trace inorganic elements, especially As, Cu, Zn, Cd, Sb, were found above the quality criteria. Selected general results of monitoring of environmental burdens focused on groundwater and surface water are presented **in the fourth article** (last paper of the issue 1/2019).

Kordík, J. & Slaninka, I.

LIST OF ACRONYMS

AFCEE	Air Force Centre for Environmental Excellence
BEI	Back-scattered Electron Images
BTEX	Benzene; Toluene; Ethylbenzene; and o-, m-, and p-Xylenes
CAVIS	Clouds, Aerosols, Vapours, Ice, Snow
CBM	Charged Body Method
CHZJD	Chemical Plants of Juraj Dimitrov
CM	CavernoMetry
CMD	Electromagnetic Conductivity Meter
COD	Chemical Oxygen Demand
DEMP	Dipole Electromagnetic Profiling
DMR	Digital Terrain Model
DNAPL	Dense Non-Aqueous Phase Liquid
EB	Environmental Burdens
EC	European Commission
EDS	Energy-Dispersive Spectroscopy
ENO	Nováky Power Plant
ERT	Electrical Resistance Tomography
EU	European Union
FNI	Phenol Index
GAL	Geoanalytical Laboratories (of SGIDŠ)
GC	Gamma-Carotage
GIS	GeoInformation System
GPH	GeoPhysical
GPR	Ground Penetrating Radar
GPS	Global Positioning System
ID	Indication criteria
IR	Infrared
ISEZ	Information System of Environmental Burdens (*Informačný Systém Environmentálnych Záťaží*)
IT	Intervention Criteria
LC	Lucas Chamber
LNAPL	Light Non-Aqueous Phase Liquid
MoE SR	Ministry of Environment
MTBE	Methyl Tert-Butyl Ether
NDVI	Normalized Difference Vegetation Index
NES	Nonpolar Extractable Substances
NIR	Near Infrared
PAH	Polycyclic Aromatic Hydrocarbons
PAN	PANchromatic
PCA	Principal Component Analysis
PCB	PolyChlorinated Biphenyls
PID	PhotoIonization Detector
POC	Points Of Compliance
PVC	PolyVinylChloride
RM	ResistiviMetry
RVA	Radon Volume Activity
SSCRI	Soil Science and Conservation Research Institute
SEI	Slovak Environmental Agency
SG	Spectrometry Gamma
SGIDŠ	State Geological Institute of Dionýz Štúr
SHMI	Slovak HydroMeteorological Institute
S-JTSK	Krovak East North (System of UniformTrigonometric Cadastral Network, *Systém Jednotnej Trigonometrickej Siete Katastrálnej*)
SLZ	Slovenské Lučobné Závody
SP	Spontaneous Polarization
STN	Slovak Technical Norm
SWIR	ShortWave InfraRed
TIR	Thermal Infrared
TM	ThermoMetry
TOC	Total Organic Carbon
VNIR	Visible Near Infrared
WDS	Wavelength-Dispersive Spectroscopy
WFD	Water Framework Directive

Slovak Geol. Mag., 19, 1 (2019), 5 – 18

1. Monitoring of Environmental Burdens Carried Out by the State Geological Institute of Dionýz Štúr Since 2012 – Main Principles and Methods

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Abstract: In the context of the Water Framework Directive (WFD) and a comprehensive water protection in Slovakia it is necessary to address the problems related to point pollution sources (so called environmental burdens). Since 2012, several projects related to monitoring of environmental burdens are carried out by the State Geological Institute of Dionýz Štúr (SGIDŠ). The aim of the projects is to design and implement the monitoring programme for 309 environmental burdens in Slovakia, to identify leakage of pollutants into the environment and their extent and to assess the trends in concentrations of pollutants. The activities carried out are in line with the standard procedures applied in the EU countries and in line with the WFD and its Daughter Directive on Groundwater Protection, which constitute the basic legal framework for the implementation of the geological task. Monitoring carried out by SGIDŠ consists of several activities: processing of archival documents and data, building of conceptual models, designing of a monitoring programme, implementation of monitoring (sampling, field measurements and laboratory works), evaluation of monitoring results.

Within the projects, a huge amount of data on water and rock environment quality have been collected and analysed. Monitoring programmes are compiled separately for each site based on the hydrogeological conceptual models. Number of proposed monitoring sites has essentially depended on the spatial extent of contamination, the number of pollution releases, type and distribution of contaminants, complexity of the hydrogeological structure and groundwater flow, behaviour of pollutants in the environment, access, sensitivity of the receptor at risk and legislative requirements. Obtained data and monitoring results contribute to a comprehensive and systematic management and gradual removal of environmental burdens as well as reduction of risks to human health and environment. The main principles and methods of monitoring of environmental burdens are discussed in the paper.

Key words: monitoring, environmental burdens, contaminated sites, methods

1.1 Introduction

In 2012 – 2015 the State Geological Institute of Dionýz Štúr (SGIDŠ) dealt with the geological task entitled "Monitoring of Environmental Burdens in Selected Sites of the Slovak Republic", whose main objective was the design and implementation of monitoring systems for 161 selected environmental burdens (EB) in Slovakia. The geological task was co-financed by the European Union/Cohesion Fund under the Operational Program Environment and the results of this geological task are summarized in the final report (Kordík & Slaninka, et al., 2015). At present, monitoring of these sites continues within the programme of sustainability of the geological task until the end of 2020. Furthermore, since October 2016 SGIDŠ has monitored environmental burdens at 83 sites as part of the geological task "Setting up the Monitoring of Environmental Burdens of Slovakia – Part 1" (a geological task co-financed by the European Union/Cohesion Fund under the Operational Programme Quality of Environment). Finally, since 2017 SGIDŠ has observed 81 environmental burdens within the sustainability of the tasks of the Section of Geology and Natural Resources of the Ministry of Environment of the Slovak Republic concerning surveys and remediation of environmental burdens solved in 2012 – 2015.

Geological works carried out in the framework of monitoring of environmental burdens focus mainly on characterizing the rock environment, including monitoring processes taking place in the area of an environmental burden, monitoring the character and properties of pollutants, as well as obtaining information on the nature of the burden itself. The character and properties of the rock environment are usually monitored on the basis of petrographic description of rock material, hydrogeological properties (distribution of aquitards and aquifers, groundwater level and its variation, direction and speed of groundwater flow, hydraulic characteristics of aquifers and aquitards, knowledge of hydraulic boundary conditions, precipitation – drainage conditions), engineering-geological properties (e.g. density index, compactness, granularity, consistency of soil and sediment, permeability), geochemical properties including isotope composition (chemical composition of rock environment, waters, bottom/river sediments, soils, air, etc.).

Monitoring of environmental burdens fulfils the programme objectives of the Government of the Slovak Republic, which are defined in the document "State Programme of Remediation of Environmental Burdens for the years 2010 – 2015 and 2016 – 2021, respectively".

In particular, the monitoring of EBs follows up the results of several geological tasks of the Ministry of Environment of the Slovak Republic. In 2006 – 2008 the geological task of Systematic Identification of Environmental Burdens of the Slovak Republic was implemented (Paluchová et al., 2008). More than 1,800 EBs (www.enviroportal.sk) have been identified in Slovakia, of which about 1,200 still pose a danger to human health and the environment. A systematic identification of the EBs also included a preliminary risk assessment of individual sites. The results of the project of Systematic Identification of Environmental Burdens were followed up in 2009 by the project "Regional Studies of Impacts of Environmental Burdens for Selected Regions" (SEI, 2010). The aim of the project was a detailed assessment of the environmental impact of environmental burdens in individual self-governing regions of the Slovak Republic. The main objectives of the geological task "Monitoring the Impact of Environmental Burdens on Geological Factors of the Environment in Selected Regions of the Western Carpathians" (Vybíral et al., 2005) were the use of new methodologies and techniques for investigation and monitoring the impact of landfills and other environmental burdens on the environment, assessing the effects of anthropogenic deposits through the risk of deposited waste and the risk of pollution of the environment, determination of qualitative and quantitative parameters of pollution, extent and degree of pollution of the rock environment and determination of trends in the spread of pollution in time and space. The use of remote sensing to monitor the impact of landfills and old environmental burdens on geological factors of environment (water, soil, river sediment, air) was evaluated by Gregor et al. (2008). System of environmental damage detection and monitoring of mining activities were processed by Vrana et al. (2005). In the years 2012 – 2015, within the tasks of the Section of Geology and Natural Resources of the Ministry of the Environment of the Slovak Republic, surveys and remediation of selected environmental burdens were carried out (monitoring of these sites continues at SGIDŠ, as mentioned above).

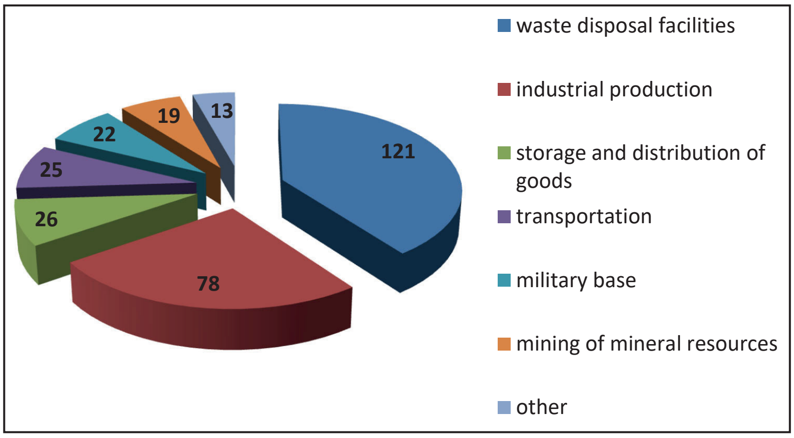

Fig. 1.1 Representation of economic activities at the assessed sites of environmental burdens

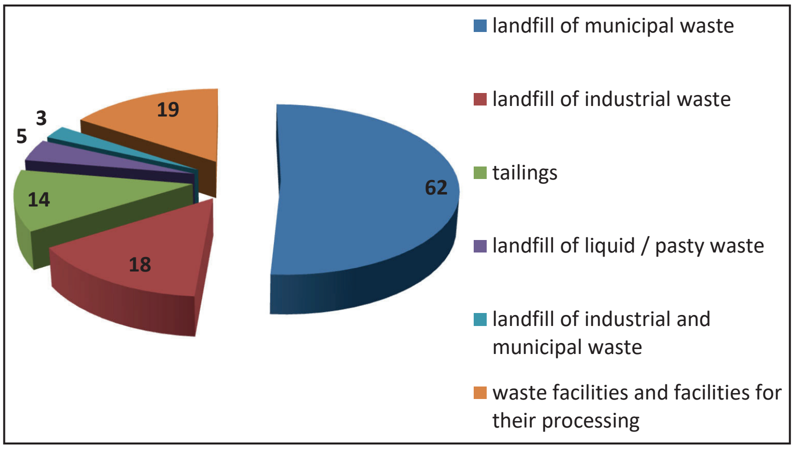

Fig. 1.2 Representation of economic activities related to waste management

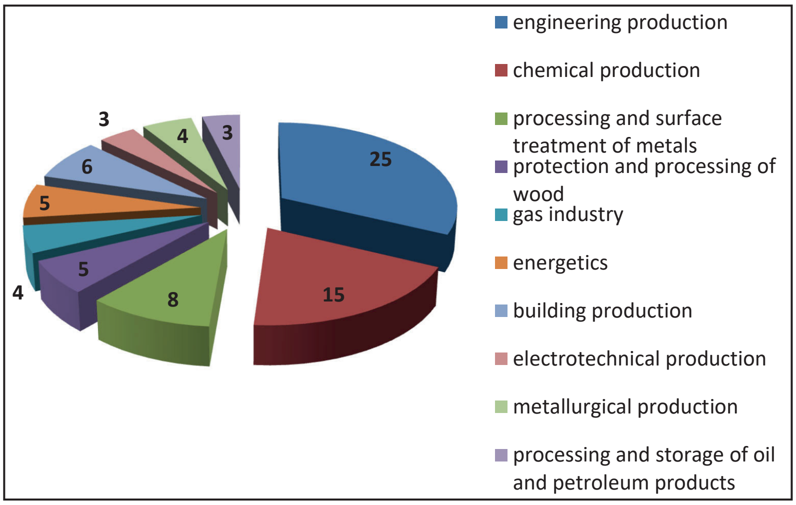

Fig. 1.3 Representation of economic activities related to industrial production

The monitored sites represent a wide range of economic activities that have been carried out in the past. The representation of economic activities in the evaluated sites of environmental burdens is shown in Fig. 1.1. "Waste management facilities" (121 sites) are the largest economic activities in the evaluated sites, followed by "industrial production'" (78 sites) and "warehousing and distribution of goods" (26 sites). This is followed by transport, consisting mainly of railway depots and stations. Into the smallest group "other" illegal discharges of pollutants are mostly placed.

Representation of economic activities in connection with waste management or industrial production, is summarized in the Figs. 1.2 and 1.3. Waste management facilities are predominantly municipal waste landfills (62 sites), waste storage facilities and treatment facilities (19 sites), industrial waste landfills (18 sites) and tailings ponds (14 sites). Industrial production is mostly represented by engineering (25 sites), chemicals (15 sites) and metal processing and treatment (8 sites).

The map of monitored environmental burdens in Slovakia, implemented by SGIDŠ, is shown in Fig. 1.4, as well as in the Annex.

In the article attention is paid to the main principles and methods applied in the monitoring of environmental burdens in Slovakia.

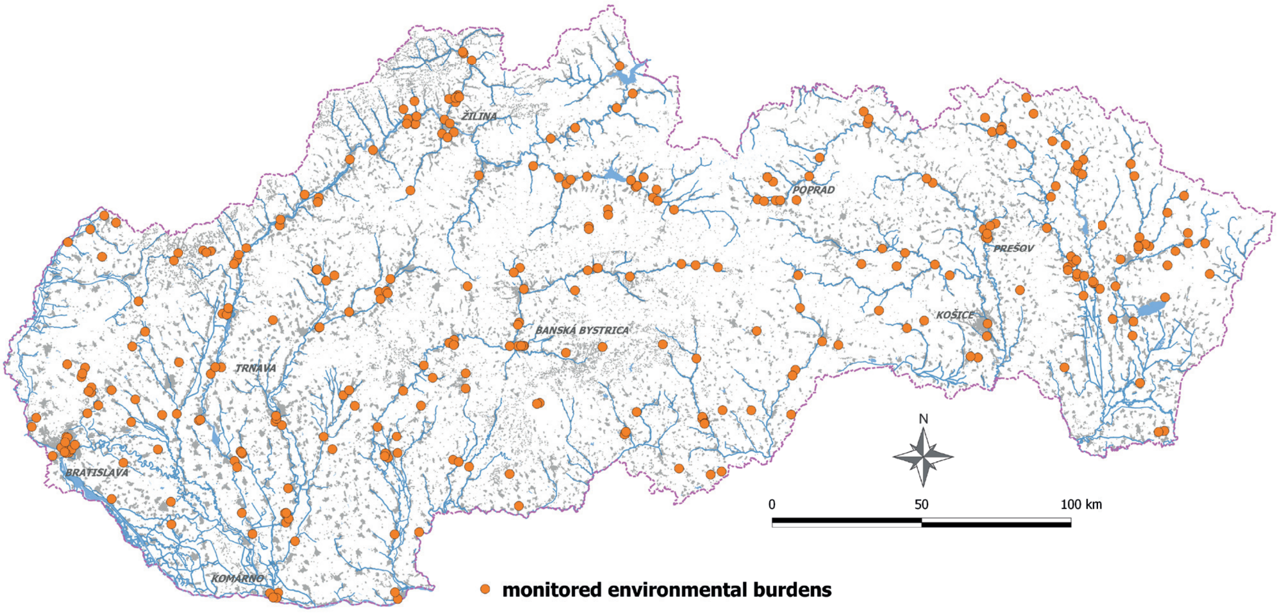

Fig. 1.4 Map of environmental burdens in Slovakia monitored by SGIDŠ

1.2 Methodological principles of monitoring of environmental burdens in Slovakia

General principles

Monitoring of environmental burden is a systematic observation of the identified environmental characteristics of a site affected by environmental burden. The main objective of the monitoring of EB is the systematic monitoring of time changes of the examined indicator, in particular the concentration of the pollutant. The monitoring involves repeated measurement or sampling and evaluation of samples taken at precisely defined sampling sites that form the monitoring network. The monitoring network represents a spatially and type-defined set of monitoring objects that are regularly observed (sampled, measured) for the purpose of EB evaluation.

Monitoring of environmental burdens is carried out **in accordance with EU legislation**, in particular with Directive 2000/60/EC of the European Parliament and of the Council of 28 October 2000 establishing a framework for Community action in the field of water policy, Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration, and a Common Implementation Strategy for the Water Framework Directive, in particular Guideline no. 17 to prevent or limit direct and indirect inputs, Guideline no. 7 on monitoring and Guideline no. 15 on groundwater monitoring. Within the framework of monitoring, geological works are carried out, which are governed by the Act of the National Council of the Slovak Republic no. 569/2007 Coll. on Geological Works, as amended, and implementing Decree of the Ministry of the Environment of the Slovak Republic no. 51/2008 Coll. implementing the Geological Act as amended.

The **specific objective of the monitoring of EB** is to identify/confirm (within a certain timeframe):

- whether there is/isn´t a leakage and subsequent spread of pollutants in the individual components of the environment,
- trends in the development of pollutant contents in the monitored components of environment, through monitoring objects at various stages of dealing with EB (monitoring, research, remediation, etc.),
- effectiveness and success of remedial measures,
- supplementary data on the extent of pollution and other, in particular time-varying parameters needed to assess the risk of impacts of EB on the environment and human health.

From the point of view of the **timing of the monitoring implementation with other stages of dealing with EB** (research, remediation), the monitoring of EB can be divided into:

- self-monitoring, independent of other activities on the EB site,
- monitoring performed in connection with exploratory works (or between different stages of the survey); after exploratory works, respectively,
- monitoring performed during the remediation process – remediation monitoring,
- monitoring carried out after the implementation of remediation,
- monitoring carried out under monitored natural attenuation.

The individual types of EB monitoring have their specificities regarding their objectives or the methods and procedures used; they are briefly listed below.

Self-monitoring

Separately implemented monitoring is used as one of the methods of obtaining information about the site with environmental burden. On the basis of the monitoring results, a further procedure for dealing with EB can be identified. It is usually necessary to apply some additional geological exploration methods (selected geophysical works, atmogeochemistry, remote sensing, screening sampling, etc.) for the purposes of the monitoring programme proposal. The design of the monitoring system is based mainly on the conditions of the rock environment and the properties of the pollutant. Most often, timely dynamic media such as groundwater and surface water are monitored. However, depending on site conditions, other media such as soils, sediments, soil air, etc. may also be monitored. The location of the monitoring objects depends on the local geological structure, the hydrogeological and geochemical properties of the rock environment, the type of contaminant and the processes taking place in the environment. The number of monitoring objects is mainly based on the extent of the original pollution and is designed to be representative towards the pollution. In simple cases, one monitoring object is proposed for monitoring of local background area, two to three monitoring objects in the source of pollution and potentially threatened area (in the direction of groundwater or surface water flow). In self-monitoring, the scope of monitoring and additional works are usually greater at its early stages when there is not enough information about the site.

Monitoring performed in connection with exploratory work

Monitoring procedures in this case serve as a guiding method for obtaining information about parameters of variable character. Monitoring thus helps to obtain information about the temporal changes of the observed indicators, which are important for meeting the investigation objectives. An example of this type of indicators is the change in groundwater level, change (e.g. seasonal) in concentration of selected indicators, amount of precipitation, water temperature, water discharge, etc. The information needed to develop a monitoring programme is obtained from the investigation results and the extent and frequency of monitoring are adapted to the objectives and requirements of the investigation.

Remediation monitoring

The scope and method of remediation monitoring is based on the applied remediation method and properties of environment. Remediation monitoring is particularly important for in situ remediation methods. The aim of the remediation monitoring is to monitor the indicators affecting the optimal application of the remediation method and to verify the effectiveness of remediation. The results of the remediation monitoring should provide sufficient information on the impact and effect of the remediation method on the rehabilitated environment, so that the conditions of remediation can be operatively guided and adjusted to optimize and improve the efficiency of remediation. The monitored medium, monitoring network (layout and installation of objects) and the extent and frequency of monitored indicators are also adapted to this goal. Utilizing the results of well-established remediation monitoring allows for more efficient remediation and can reduce the overall cost of remediation.

Monitoring after remediation

Monitoring after remediation (post-monitoring) is proposed after application and completion of remediation intervention on site. The aim of this monitoring is to observe, control and verify the results of remediation over a longer period of time. The post-monitoring demonstrates the long-term achievement of defined remediation limits. Long-term monitoring is of particular significance, especially in the case, where the environmental conditions or the type of contaminant assume that the effect of so-called rebounding can occur in the water (increasing the concentration of the pollutant). The draft of monitoring programme is based on remediation results, which means that the representative monitoring objects are selected for local natural conditions, contaminant type and remediation type. The main pollutants, their potentially hazardous degradation products and, where appropriate, the substances used for remediation are usually monitored. Monitoring frequency is usually higher than in regular monitoring (4 times a year or more). The recommended minimum monitoring period is two years. Remediation limits for specific reference sites or monitoring objects are used for interpretation of analytical results.

Monitored natural attenuation

Monitored natural attenuation uses natural chemical, physical and biological processes taking place in the rock environment (without active human intervention) resulting in reduction of the amount, volume and concentration of pollutants or conversion them into less dangerous and less toxic substances (e.g. AFCEE, 1999a, 1999b; Krupka & Martin, 2001; Gilmore et al., 2006). Natural attenuation processes can consist of biodegradation, dispersion, dilution, sorption, volatilization, radioactive decay, chemical or biological stabilization, hydrolysis, dehydrohalogenation, evaporation and transformation, or decomposition of a pollutant. Monitored natural attenuation has been successfully applied in the areas with various contaminants in the aquatic environment such as petroleum hydrocarbons, chlorinated hydrocarbons, MTBE, explosives, volatile organic compounds, as well as inorganic substances such as nitrogenous substances, metals (Hg, As, Se), radionuclides and others. The main objective of natural attenuation monitoring is to control the movement of the pollutant in the environment as well as to monitor the current state of contamination and to evaluate the future evolution of the degradation processes. A more comprehensive description of the monitored natural attenuation is beyond the scope of this article and forms the content of specific documents devoted to remediation methods (e.g. Frankovská et al., 2010).

The design and implementation of monitoring has certain specifics for a particular **type of environmental burden**. In particular, the number and type of monitoring objects, their location, the extent and frequency of the monitored indicators are changing.

For ***landfills***, it is important to find out information about the type of waste deposited when designing monitoring. In the case of municipal and construction waste, the usual monitored pollutants are indicators reflecting the content of organic substances (originating from organic waste material) and their decomposition products, such as TOC, NH_4^+, COD, etc. These are accompanied by reduced dissolved oxygen and low redox potential. In addition to the above-mentioned indicators, the values of specific electrolytic conductivity and contents of chlorides, boron, sodium, potassium, sulphates, phosphates and some trace elements (chromium, lead, zinc, arsenic) are often increased. In the case of industrial waste landfills, monitored indicators need to be supplemented depending on the chemical composition of the waste deposited (e.g. group and specific organic indicators or other trace elements).

For ***industrial sites***, a sufficient degree of site review is very important for monitoring design. Based on the investigation results, location of monitoring objects, the scope and frequency of the monitored indicators are set. This is due to the wide variety of pollution types and the possibility of multiple sources of pollution on the site, often with different pollution patterns. NEL, BTEX, chlorinated hydrocarbons, PAHs, phenols, cyanides, PCB, inorganic trace elements (Cr, Cd, Hg, As), etc. are monitored most frequently.

Mining sites are a specific type of environmental burdens. Their occurrence in Slovakia is related to the prosperous mining activity in the past. This includes, in particular, tailings, heaps, tunnels, etc. The most frequently monitored indicators are potentially toxic elements such as As, Sb, Cu, Pb, Zn, Cd, Ni, Hg. Pollution is often manifested by reduced pH (sulphides weathering) and the formation of ferric ochres in effluent waters.

The ***transport areas*** are mainly railway depots and stations. Especially the pollution caused by the leakage of fuels used in the transport, especially of the oil nature, may appear in their vicinity. Therefore, the content of petroleum products in the rock environment and groundwater is monitored. Monitored substances include petroleum products observed through nonpolar extractable substances, in addition microbial colonization of the environment relevant to oil degradation and other important environmental properties (dissolved O_2, Eh, pH, water temperature, nutrients, etc.).

Within ***agricultural areas***, pollution of groundwater and surface waters is most often manifested by waste products of animal production. Pollution is usually monitored through indicators of nitrogen (NH_4^+, NO_2^-, NO_3^-, N_{org}, N_{total}) and phosphorus (P_{total}, PO_4^{3-}), TOC, COD, dissolved oxygen content and redox potential.

Pesticide depots have potential for pollution of the rock environment and groundwater by improper storage of pesticides. In the framework of monitoring, it is necessary to monitor their possible leakage through the analysis of relevant pesticides and, where appropriate, their degradation products.

1.3 Monitoring of environmental burdens carried out by SGIDŠ

Scheme of the EB monitoring implemented by SGIDŠ, modified according to the Common Implementation Strategy for the Water Framework Directive, Guideline no. 17 to prevent or limit direct and indirect inputs, is shown in Fig. 1.5. Some important facts arise from the scheme. Data acquisition and implementation of individual monitoring activities are a cyclical process that should be repeated systematically. Based on increasing monitoring information, conceptual models and monitoring programme of individual sites can be updated and optimized at some point in time.

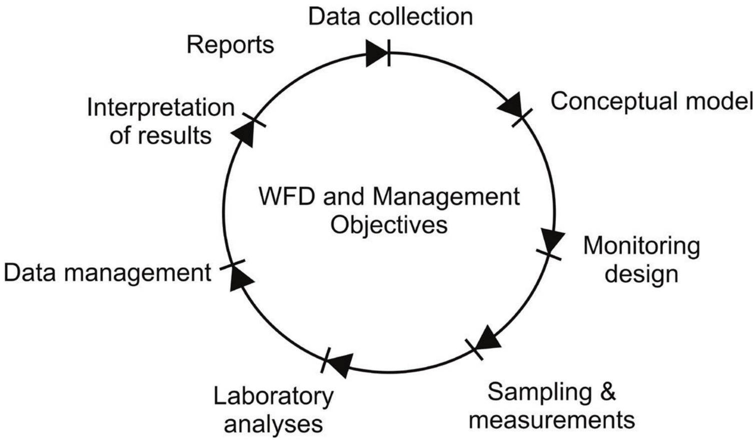

Fig. 1.5 Procedure of monitoring of environmental burdens (adapted according to the Common Implementation Strategy for the Water Framework Directive, Guideline 15 Groundwater Monitoring Guidelines)

In the context of the above mentioned, the following activities are carried out within the framework of the EB monitoring by the SGIDŠ:

1. collection of information – archival excerption, reconnaissance of sites, creation and updating of a specific geological information system for EB monitoring,
2. compiling and updating of conceptual models for each site,
3. design and update of the monitoring programme,
4. sampling and field measurements – sampling of water and solid materials (soils, rocks, river/bottom

sediments), soil air measurements (atmogeochemistry),

5. laboratory work – analysis of water and solid materials, isotope analyses, engineering-geological assessments and special analyses,
6. Data management and evaluation of monitoring results of EB – final report (Kordík & Slaninka, et al., 2015), annual monitoring reports, specific interim reports.

Due to the implementation of EB monitoring also at sites with a low level of knowledge, some supplementary methods and procedures of investigation were implemented – mainly geophysical works and remote sensing methods.

Archival excerption

Information in the framework of archival excerption was obtained mainly from the following information sources:

- Department of Geofond and Department of Geological Information Systems of SGIDŠ (www.geology.sk),
- information system of environmental burdens, including the Register of Environmental Burdens (https://envirozataze.enviroportal.sk/),
- competent environmental authorities.

As part of the study of archival documents, it turned out that the degree of examination of individual sites of EBs varies. Although detailed exploration works has been carried out in most sites in the past and there is a relatively large amount of data available, no documentation was also available for some sites. These facts were subsequently taken into account when completing the monitoring network and the design of geological works.

Reconnaissance of sites

Representativeness and technical condition of existing boreholes or other existing monitoring objects were verified within the framework of site reconnaissance of the relevant site. All documented objects were georeferenced by GPS and photo documentation was made. Where possible, field measurements (specific electrolytic conductivity, pH, water temperature, groundwater level, etc.) were carried out.

Information system of monitoring of environmental burdens

Due to the processing of a large number of data of various types, a specific geological information system of monitoring of environmental burdens was created in 2012. The text and data parts of the system are used to store general information of various formats obtained within the monitoring, especially for storing various text and graphic files in the directory structure. The database and GIS part of the information system serves to manage database and GIS formats in precisely defined structured online form. The database of EB monitoring is centrally built. The database's technical platform is the PostgreSQL 9.3/PostGIS 2.1 relational database system. It consists of a set of interconnected tables, between which there are defined relationships (relational model). Some of the tables contain so-called geometry that allows the table to be mapped, i.e. to be viewable in some GIS programme

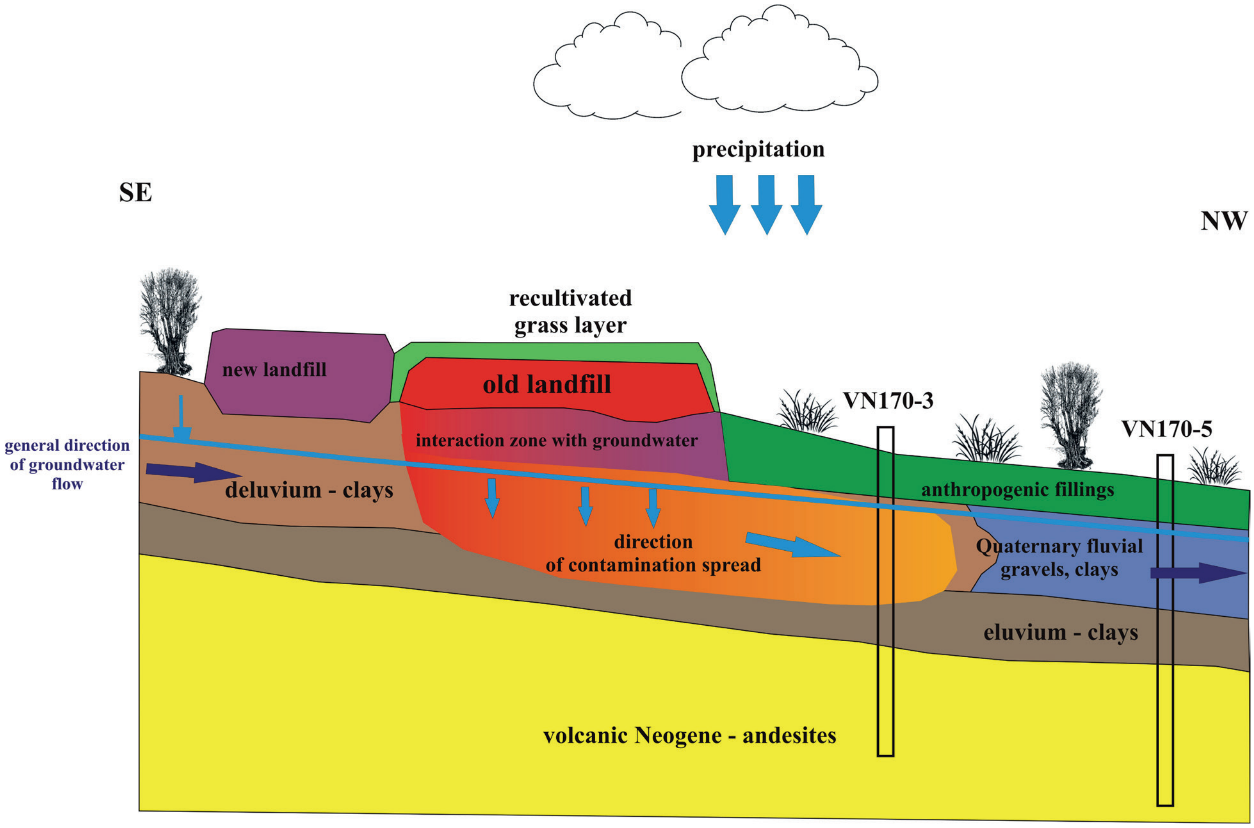

Fig. 1.6 Example of conceptual model – site Žiar nad Hronom – Horné Opatovce landfill

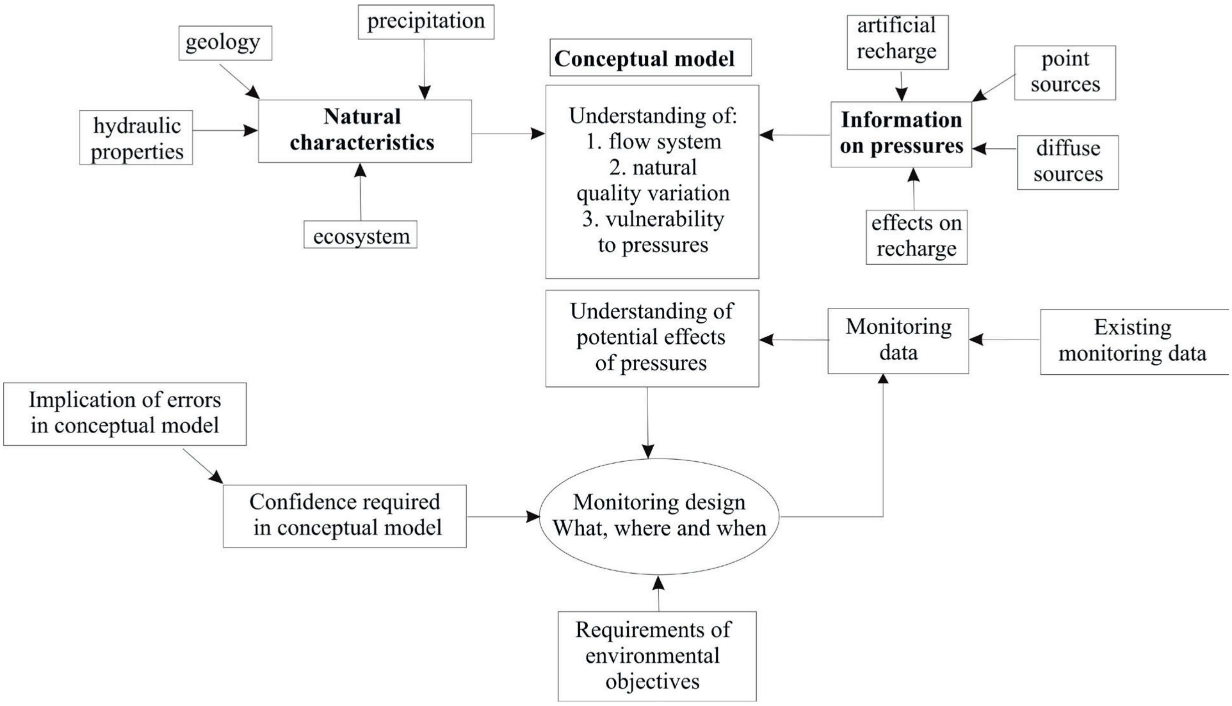

Fig. 1.7 Relationship between the conceptual model and the monitoring programme proposal (adapted according to the Common Implementation Strategy for the Water Framework Directive, Guideline 7 Monitoring)

(mainly MapInfo Professional licenses are used in SGIDŠ or the free QGIS programme).

Conceptual models

Information obtained in the framework of archival excerption and site reconnaissance was transformed into initial conceptual models of individual sites. The conceptual model represents a description of natural and secondary-induced environmental properties, physical and chemical processes taking place in the area of interest and the potential risks arising from contamination. In the conceptual model, a reference (background) area is specified "above" the source of pollution that is not affected by EB; the source of pollution (relevant information on its spatial extent, history and type of site activity, etc.); pollution transport (information on key properties and processes affecting pollution spread) and receptors at risk of pollution. Initial conceptual models formed the basis for compiling a monitoring programme. Based on the new findings during the monitoring, conceptual models are updated at selected sites of the EB, which also involves regular optimization of the monitoring plan. Example of conceptual model is presented in Fig. 1.6 and relationship between the conceptual model and the design of the monitoring programme is shown in Fig. 1.7.

Supporting activities – geophysical work and remote sensing methods – were used in the preparation and implementation of monitoring work.

Geophysical works

The aim of **geophysical work** was to refine the spatial structure of the rock environment; to determine the thickness of the coverings, the relief of the impermeable subsoil and the course of the failure zones; to determine the groundwater flow direction and rate and the implementation of additional logging in selected monitoring wells. Geophysical works were divided into preparatory works (archival excerption, field reconnaissance), field work of the first stage (CMD screening carried out at all sites; design of the works of the 2nd stage), field work of the second stage (implementation of additional geophysical measurements at selected sites) and drawing up partial final reports.

The aim of the CMD screening was to determine the electromagnetic conductivity and susceptibility of local rocks, soils and deposits at three depth levels (2.2 m, 4.2 m and 6.7 m) simultaneously. A measuring interval of 1 second was used. The measured quantities were the apparent resistivity (apparent specific conductivity) and the in-phase component, which is proportional to the magnetic susceptibility of local rocks and deposits.

Geophysical profiles were defined on selected sites in the 2nd phase and measurements were made by at least one of the methods – multicable, georadar, spontaneous polarization, HG variant of charge body method, gamma spectrometry, emanation measurements (RVA – ^{222}Rn) and logging measurements (in the range of cavernometry, thermometry, differential thermometry, resistivimetry, gamma-ray log and, if possible, electro log). The results of geophysical measurements help to optimize the location of sampling and drilling works. Geophysical works were carried out in 2014 and 2015.

Remote sensing

The main objective of the remote sensing was to analyse, interpret, and synthesize remote sensing data (multispectral satellite imagery and detailed aerial imagery from different time periods) over selected environmental burdens. By means of remote sensing methods, the boundaries of EB and their development over time were monitored, e.g. search for centre of pollution. In the frame of interpretation of results, overall and spatial extent of environmental burdens were established as well as the historical development of pollution based on aerial and satellite images with very high and high-resolution was described and monitored. Results achieved by remote sensing have been proven by field work and have been used to update conceptual models and monitoring programmes. Remote sensing was conducted in 2014 and 2015.

Monitoring programme

Depending on the degree of site review, it is necessary to set the scope of the work in site monitoring to get all the information necessary for the design and implementation of the monitoring programme, which can be time-consuming and expensive. The advantage of setting up a monitoring programme is therefore the already existing sufficient information base on the site resulting from previous investigation. It is possible to monitor practically all relevant geological media within the monitoring work. However, in practice, more dynamic, time-varying media, such as groundwater, surface water, seepage water and soil air are most commonly monitored. Except for the above mentioned, other supplementary media such as e.g. river and bottom sediments, soil, dust fall, rainfall, etc. can be observed.

The draft monitoring programme is based on assumed points of contamination release into ground/surface water and takes into account the direction of ground/surface water flow. At least one observation object is located in an area unaffected by the EB (to determine the background characteristics of the environment). The frequency of observation and the density of the monitoring network take into account the behaviour of pollutants in the environment (e.g. residence time, migration characteristics, formation of degradation products, etc.) and the monitored indicators are indicative of the type of pollution. When dealing with environmental burdens, it is necessary to take into account the temporal and spatial variability of pollution. The monitoring programme is divided into a *monitoring network* (the result is a list of monitoring points based on the concept and objectives of the monitoring) and a *monitoring itself* (the range of monitored parameters, frequency of monitoring, method of archive of monitoring results). Based on new monitoring information, the monitoring programme is reviewed once a year and conceptual models of selected sites can be updated as well.

The establishment of the monitoring network in relation to the input of pollutants into the environment is based on the ***concept of so-called points of compliance*** (POCs), which should provide information on possible contamination from the points of leakage of pollutants to the environment to predicted receptors/recipients (e.g. water supply, surface flow, etc.). The concept of POC is shown in Fig. 1.8.

POC 0 is located at the bottom of the source of contamination in the unsaturated zone. It is a point of leakage of a pollutant into the environment and therefore the aim is to find out whether the pollutants leaked into the rock environment, what substances are involved and to estimate the risk of their transfer into groundwater. In accordance with the Directive of the MoE SR no. 1/2015-7 for the preparation of risk analysis of contaminated area, the criterion of the quality of the rock environment and soil is usually set for POC 0 at the IT value level for the given contaminant.

POC 1 is located at the groundwater level for checking whether pollutants penetrate into groundwater (zone of saturation). In POC 1, the concentration of substances in groundwater is determined, while in POC 0 the properties of the source of pollution are monitored. In accordance with the Directive of the MoE SR no. 1/2015-7, the criterion of the quality of groundwater is usually set for POC 1 at the IT value level for the given contaminant.

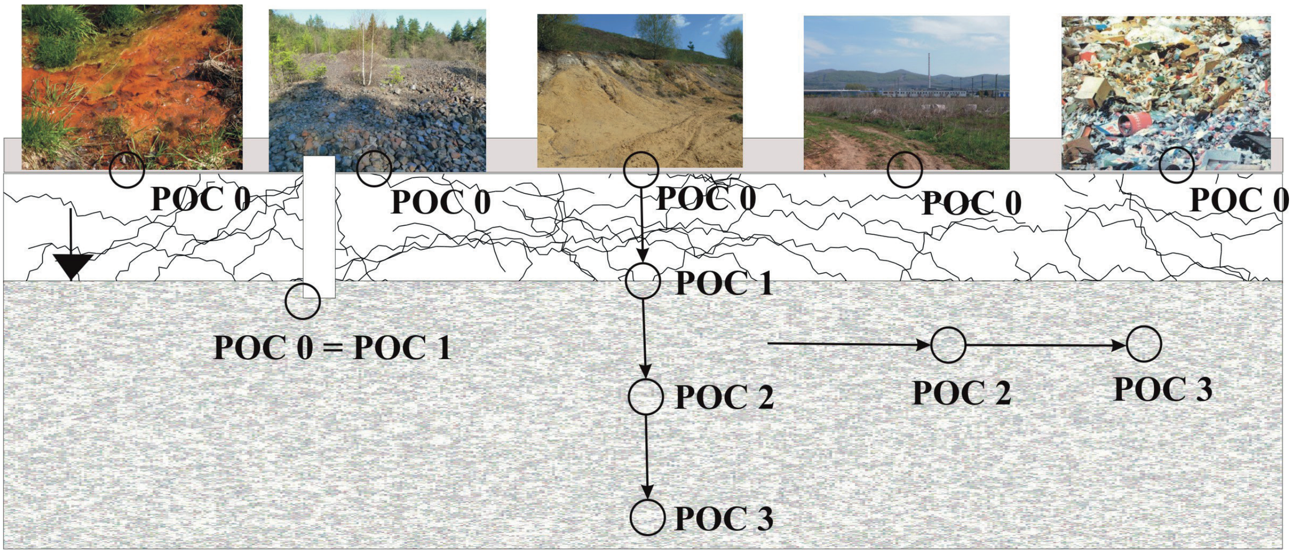

Fig. 1.8 Concept of points of compliance (modified according to the Common Implementation Strategy for the Water Framework Directive, Guideline 17 to prevent or limit direct and indirect inputs)

POC 2 is located in the direction of the hydraulic gradient between POC 1 and receptors (its aim is to provide early warning that the receptor may be adversely affected). In accordance with Annex no. 6 to the Directive of the MoE SR no. 1/2015- 7 is determined according to the principle “if there is no pollution receptor within 100 m from the source in the direction of contamination spread, the POC 2 is determined at this distance”. The groundwater quality criterion is generally determined at the IT value level for the contaminant.

POC 3 is used to monitor the impact of pollution at the receptor site. In accordance with Annex no. 6 to the Directive of the MoE SR no. 1/2015-7 can be determined, for example, with regard to the existence of a protected area (e.g. water supply protection zone). For such POC 3, the groundwater quality criterion is usually determined at the level of the limit value for a given pollutant according to the Decree of the Ministry of Health of the Slovak Republic no. 247/2017 Coll., laying down details on drinking water quality, drinking water quality control, monitoring and risk management programme for drinking water supply. In case of another type of protected area being threatened, the groundwater quality criterion is determined according to the regulations applicable to the type of protection. The POC 3 can also be designed on the shore of surface water. The groundwater quality criterion must be such that groundwater entering the surface water does not cause unacceptable deterioration of surface water quality (pursuant to Government Decree No. 269/2010 Coll. laying down requirements for achieving good water status).

Sampling and field measurements

Environmental burdens very often affect the condition and quality of groundwater and surface water. Water is usually the main transport medium through which pollution is spread. Monitoring of EB can also be considered as a supplementary monitoring for basic and operational monitoring in Slovakia, which is carried out by SHMI within the state monitoring network (it is required by the Water Framework Directive for the assessment of the chemical status of groundwater bodies and water bodies).

Representative sampling is one of the most important steps in getting the correct monitoring results. As part of the monitoring of EB, the most commonly used sampling is so-called a point sample (the sample is taken at a certain time and at a specific location). Samples are mainly taken from the monitoring boreholes by pumping (submersible or suction pumps), exceptionally by a bailer (hand-operated equipment). Before sampling, it is important to perform a groundwater level measurement and well cleaning. The borehole is cleaned up to stabilize the monitored field indicators. According to several sources, it is recommended to pump the water volume equal to three times the borehole volume. It is essential to avoid the influence of stagnant water in the well, whose properties may differ from natural conditions in the aquifer. The pumps are used for sampling with the possibility of regulating the pumping capacity, which allows the flow rate to be adjusted during sampling so that the natural regime in the borehole is not disturbed and the borehole is also sufficiently cleaned (generally lower yields are recommended). Material of the pump and other facilities must not adversely affect the quality of the sample taken. The following pumps are usually used to sample groundwater: 12 V DC centrifugal submersible sampling pumps (Manufacturer: Ecotechnika, Ltd. - Model Gigant GR 4; Fig. 1.10), submersible sampling centrifugal pump with a maximum discharge height of 90 m resp. 40 m (Manufacturer: Eijkelkamp Agrisearch Equipment BV Model: Submersible pump MP1) and portable peristaltic pump for groundwater and air sampling with internal 12 V DC battery and microprocessor unit (Manufacturer: Eijkelkamp Agrisearch Equipment BV Model: Peristaltic pump 12 Vdc). In hydrogeological boreholes, dynamic

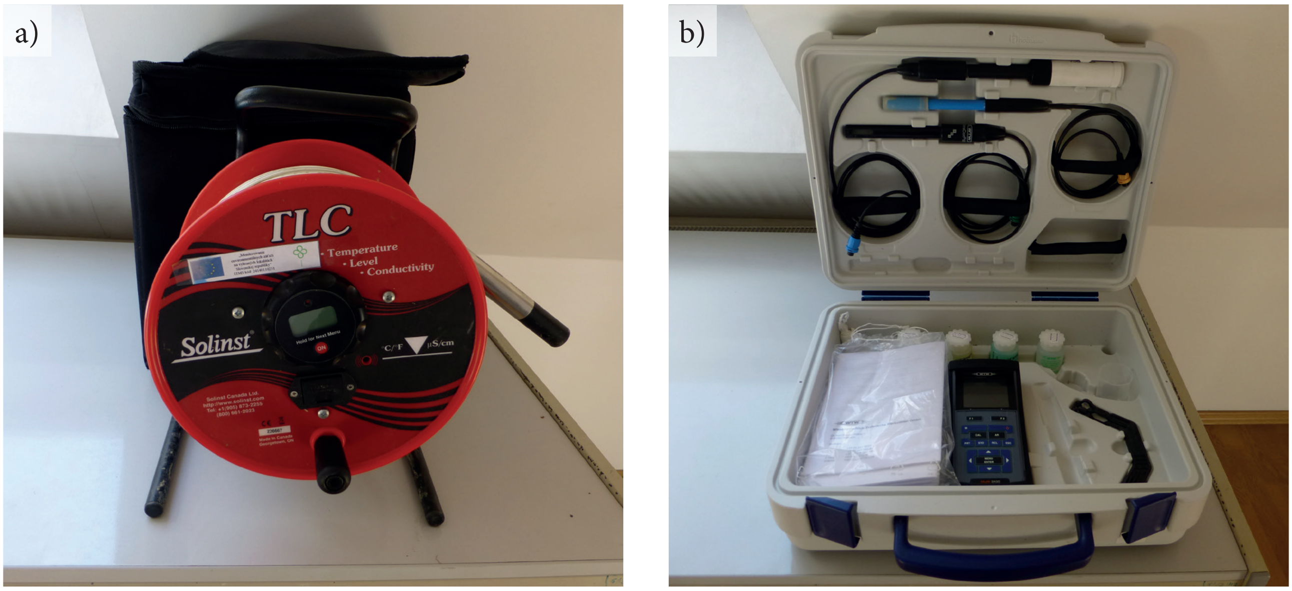

Fig. 1.9 Field measuring instruments: a) portable multimeter for measurement of pH, Eh, temperature, dissolved oxygen content and specific electrolytic conductivity, b) groundwater level meter enabling measurement of temperature and specific electrolytic conductivity of water

Fig. 1.10 Sampling and measurement of indicators using multimeter and flow cell

Fig. 1.11 (a) Automatic groundwater level and temperature measurement device plugged into a USB data reader, (b) 12 V DC centrifugal submersible sampling pumps Gigant GR 4 with regulation of flow rate

groundwater sampling is mostly performed. The boreholes are pumped until the physico-chemical parameters (temperature, pH, specific electrolytic conductivity, dissolved oxygen, oxygen saturation degree) are stable. Surface water samples are taken by a retractable telescopic rod. Sampling work is always consulted with a laboratory performing analytical work to avoid undesirable change in sample collection and transport to the laboratory. Water samples are transported in the bottles provided by the laboratory.

Water sampling is performed on the basis of the procedures specified in the relevant Slovak technical standards (STN) of the STN EN ISO 5667 series. The following physico-chemical properties are usually determined directly in the field: water temperature, air temperature, pH, specific electrolytic conductivity (at 25 °C), dissolved oxygen content, oxygen saturation in percentage, groundwater level (if relevant). Field measurements are mostly performed by WTW Multi 3430 Set F in a flow cell (Figs. 1.9 and 1.10). The groundwater level measurements are carried out by a portable equipments with the possibility of conductivity measurement: Solinst – Model 107 TLC (Fig. 8) or a G30 portable level meter. An automatic level-logger is used as a special device to record groundwater level data (based on pressure change) and groundwater temperature at regular set intervals (Fig. 1.11). For measuring the interface of the LNAPL or DNAPL, the portable device Solinst Canada Ltd. – Model: Interface Meter Model 122 (through infrared optical interface measurement detector, 1 mm accuracy) is used.

In the case of sediments, **active stream sediments** potentially affected by EB are monitored. Besides active stream sediments, the chemical composition and quality of bottom sediments of water reservoirs is monitored. Sampling of sediments follows the standards “STN ISO 5667-12 Water quality – Sampling – Part 12: Sampling instructions for bottom sediments” and “STN ISO 5667-15 Water quality – Sampling – Part 15: Guidelines for the preservation and handling of sludge and sediment samples.

The top layer of sediment (fine fraction) is collected, which indicates the actual deposited material and the current state of contamination. The upper sediment layers (mostly limited in the range of 5 – 10 cm) form the environment of benthic organisms and protect ecosystems, which are among the main objectives of the Water Framework Directive.

To a less extent, the chemical composition and quality of **soils** are monitored. The subject of soil sampling (in the work carried out by SGIDŠ) is the surface horizons of soils: cultured arable horizon 0 – 20 cm, humus horizon 0 – 10 cm. Soil sampling is governed by specific methodological guidelines (Čurlík et al., 1998) and in accordance with ISO standards, e.g. ISO 10381-Soil sampling.

The **drilling cores** were also sampled for the chemical analysis (boreholes constructed in the framework of the EB monitoring projects in 2014 and 2015).

Sampling and field measurements are recorded in the sampling protocols (water, soil/rock, sediment). These protocols are prepared beforehand and contain all the information relevant to the correct identification of the sample and the conditions in the field during the measurement and sampling.

Laboratory works

Laboratory analyses of **water samples** are done according to a proposed monitoring programme. Laboratory analyses of water are realized in Geoanalytical Laboratories of SGIDŠ (GAL), Regional Centre Spišská Nová Ves. The most commonly analysed parameters in waters are basic inorganic indicators (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, NO_3^-, NO_2^-, Cl^-, SO_4^{2-}), trace elements (As, B, Cd, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Sb, Zn, CN^-, F^-), group organic parameters (total organic carbon, non-polar extractables such as the hydrocarbon index, sum of polyaromatic hydrocarbons, extractable organic halogen derivatives, etc.), organic substances (aliphatic and aromatic organic hydrocarbons, polychlorinated biphenyls, chlorinated hydrocarbons, pesticides, mineral oils and petroleum products).

To a less extent, **isotope analysis** according to standard methodologies are carried out in the Laboratory of Isotope Geology SGIDŠ – namely determination of O and H, S in sulphates, N and O in nitrates,, $^{13}C_{DIC}$. The knowledge of isotopic composition brings original knowledge to the pollution characteristics: identification, estimation of speed and direction of contamination spread, and assessment of qualitative and quantitative changes during contamination spread. At present, environmental isotopes are used in the issue of EB monitoring in Slovakia, e.g. in monitoring the impact of pollution from landfills of several generations, determining the residence time of rainwater in the EB area, monitoring the pollution leakage from EB isolated by underground sealing walls, determining the vertical chemical stratification of water affected by contaminants from EB, monitoring the origin (genesis) of water.

Analyses of **solid materials** (sediments, soils, rock environment) are carried out in Geoanalytical Laboratories of SGIDŠ (Regional Centre Spišská Nová Ves) in accordance with valid standards and methodologies that have been developed and validated in the laboratory. The most commonly analysed parameters in solid materials are: total organic carbon, total contents of trace elements (As, Cr, Cd, Cu, Ni, Pb, Hg, Sb, Se, V, Zn) and content of organic contaminants (non-polar extractable substances, volatile aliphatic hydrocarbons, volatile aromatic hydrocarbons, polyaromatic hydrocarbons, polychlorinated biphenyls, organochlorine pesticides).

Monitoring of soil air composition (**atmogeochemical measurements**) is used especially in the case of old landfills or in the case of contamination of the rock environment with organic substances containing volatile components. In the case of landfills, the main landfill gases (methane, carbon dioxide, oxygen, hydrogen sulphide and hydrogen) are monitored. In the case of organic pollution of the rock environment, the volatile components of pollution are monitored, e.g. substances of the BTEX group, volatile organic compounds, etc. Soil air is monitored by means of drilled or hammered atmogeochemical probes using special field measuring instruments or samples are taken into special sorption tubes and the analysis is carried out in the laboratory. The density of the measured points is adapted to the expected size of the gaseous source. The measurements carried out by SGIDŠ use the Dräger X-am 7000 measuring unit, fitted with detectors for the determination of CH_4, CO_2 and O_2 [vol. %] or ECOPROBE equipment, equipped with detectors for determination of volatile organic substances content.

Some samples of slag material and fly ash were prepared for **petrographic and mineralogical research**. Samples were analysed on an electron microanalyzer CAMECA SX 100 at the Department of Special Laboratories of the SGIDŠ in Bratislava. Back-scattered electron images (BEIs) were scanned with this instrument, allowing the study of sample details unnoticed or difficult to distinguish in an optical microscope. Using the EDS (energy-dispersive spectroscopy) method, the chemical elements present in the sample were identified. The contents of these elements in very small sample volumes (so-called point chemical analyses) were determined by the WDS (wavelength-dispersive spectroscopy) method. The aim of microanalysis is usually to detect the presence of mineral phases reflecting the specific physico-chemical conditions in the waste material (e.g. carbonates, sulphides or sulphates, Fe oxides/hydroxides, Al oxides/hydroxides, Mn oxides/hydroxides or other specific phase systems); detect the presence and content of heavy metals; identify the presence and nature of potentially unstable phases that would undesirably affect the chemical system in a hypergene environment and thereby controlling the migration of pollutants.

Evaluation of results

The first phase of EB monitoring solved in the years 2012 – 2015 as part of the financial contribution of the Operational Programme Environment was completed by the **final report** (Kordík & Slaninka, et al., 2015), which is available to the public in the Geofond archive of SGIDŠ. The results of the work carried out in the years 2016 to 2018 are summarized in the **annual monitoring reports**, which are submitted to the EU Funds Section of the Slovak Environment Agency.

The information gathered during the monitoring of environmental burdens is also **continuously processed and evaluated**, and the monitoring programmes for the subsequent period are adjusted according to the results. The aim is to identify and evaluate possible sudden changes of concentrations of monitored indicators and negative trends in the development of the contents of the monitored indicators. Graphical data processing includes visualization of results into map data, using various interpretative procedures. The spatial interpretation procedures used include interpolation of measured monitoring values (e.g. groundwater levels, contents of selected chemical indicators) into the area. Another standard approach used to interpret results is statistical processing (basic descriptive statistics, or correlation and regression analysis).

In terms of legislation, the results of groundwater and rock environment analyses are evaluated in accordance with the Directive of the Ministry of the Environment of the Slovak Republic no. 1/2015 – 7 for the preparation of risk analysis of contaminated area. Indication and intervention criteria are given in the Directive no. 1/2015 – 7, where:

- Indication criterion (ID) is the concentration limit of a pollutant determined for soil, rock environment and groundwater, the excess of which may endanger human health and the environment; this situation requires monitoring of the polluted area.
- Intervention criterion (IT) is the critical concentration level of a pollutant determined for soil, rock environment and groundwater, the excess of which in a given land use scenario assumes a high likelihood of endangering human health and the environment. A detailed geological investigation of the environment with preparation of risk analysis is necessary to carry out in the contaminated area.

Hydrogeological and geochemical modelling is also used to solve problems of groundwater flow, contaminant transport and geochemical processes. The process of construction of **hydrogeological models** is based on the conceptual model, the definition of the hydrogeological situation (reference/infiltration area of groundwater, general directions of groundwater flow, regime changes of flow), the definition of climatic and hydrological characteristics of the area, the characteristics of the contaminants and the spatial distribution of contamination, setting of character and purpose of hydrogeological model, selection of input data with respect to model purpose. The construction of hydrogeological models is carried out mainly using the FEFLOW 6.0 software (Finite Element subsurface flow and transport system) from DHI-WASY software. Models of contaminant transport are based on the transfer of a defined contaminant by groundwater flow. The transport mechanism is set with an assumption that contamination is a dissolved component in groundwater. The scale of model approximation is based on the density and quality of input data. Contamination transport is usually chosen as a pessimistic scenario in which maximum contaminant concentration is included in models. **Geochemical models** represent an important interpretative tool in solving the issues of water genesis, the study of transport and migration of pollutants in the environment. Geochemical modelling is realized through the freely available PHREEQC model (Parkhurst & Appelo, 1999).

Conclusion

The results of monitoring of environmental burdens allow relevant authorities to take flexible measures to minimize risks and damages, set targets and scope for a detailed or additional investigation of EB, propose preventive or remedial measures (removal of pollution sources, remediation of groundwater and soils), etc.

The paper presents the main principles and methods used in monitoring of environmental burdens in Slovakia. From the above mentioned overview, the complexity of the problem is obvious. The monitoring of EB involves a wide range of activities, from initial site information collection; to preparation of conceptual models and site monitoring programmes, sampling, field measurements and laboratory work; to data management and evaluation of results. Methodological procedures for EB monitoring implemented by SGIDŠ are summarized in more detail in Kordík & Slaninka et al. (2015).

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2. Use of Applied Geophysics in Monitoring of Environmental Burdens

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Abstract: Old environmental burdens represent a societal problem that must be addressed urgently. Generally, this term refers to old waste dumps, old mining works, various heaps, tailings ponds and other objects (not only) of old mining works, areas contaminated by military activity, but also other sources of pollution (industry premises, various pipelines, (agricultural) yards, manure yards, ...), which may pose a significant source of groundwater and surface water, rock environment and air pollution. This can ultimately result in a threat to human and animal health, but also in the deterioration of the stability of the landscape ecosystem.

When investigating old environmental burdens, the methods of applied geophysics are advantageously used for their efficiency and speed of screening in the area of objects of interest. The results of these works provide information about the studied area indirectly – based on the analysis of various (geo)physical fields and physical parameters of the rock environment.

Outputs of interpretation of geophysical measurements enable to optimize localization of other activities (sampling and drilling works, etc.) and thus can significantly contribute to the solution of the problem of environmental burdens.

Key words: applied geophysics, environmental burden, monitoring

2.1 Introduction

The issue of creation and protection of the environment is very extensive and to varying degrees it concerns practically all activities of the human population. However, it can be stated that in the last decades it has been ranked among priority areas, which is an undeniably positive trend from the environmental point of view.

In the study and monitoring of various environmental parameters geosciences dealing with the survey of the geological environment are widely used. Several of the problems can be effectively solved by a rational and economically designed set of geophysical (GPH) methods and methodologies.

However, this issue cannot be more generalized and each GPH measurement at a particular site/object should be modified according to specific field, structural-geological, hydrogeological, engineering-geological, etc. conditions.

The geophysical methods provide information about the surveyed area indirectly – based on the analysis of a number of physical fields and parameters of the geological environment. We rank them mostly in the so-called group of non-destructive methods that do not require significant interventions in the natural environment.

When researching various environmental burdens (landfills, tailings ponds, contaminant leaks, etc.), the GPH works are used mainly due to their effectiveness and the possibility of relatively rapid point/profile/area survey directly in the area of an environmental burden (EB), or in its (wider) neighbourhood.

Thus, in the first phase, they can help to optimize the situation of other exploratory works (probes, wells, sampling points of different types of samples, etc.) and in the next stages allow interpolation/extrapolation of information obtained from direct methods of valuation of the EB.

2.2 Methodology and solution procedures

Due to the large scale of the GPH measurements – 161 localities situated unevenly across the whole territory of Slovakia (Kordík & Slaninka et al., 2015) – the works were divided into five sites within which individual organizations carried out the GPH survey work.

In parallel, five organizations participated in the geological task solution: SENSOR, s.r.o. Bratislava (Bratislava + Trnava regions); ESPRIT, s.r.o. Banská Štiavnica (Banská Bystrica region); BHF environmental, s.r.o. Bratislava (Trenčín + Žilina regions); KORAL, s.r.o. Spišská Nová Ves (Košice + Prešov regions) and DEKONTA Slovensko, s.r.o. Bratislava (Nitra region). In addition, the employees of AG&E, s.r.o. Bratislava participated in the GPH work.

As all geosciences the methods of the applied geophysics have also their limits, which have to be handled in searching and exploring not only the old EBs. The limits often result from the physical fundamentals of the individual methods, and under unfavourable circumstances, some methods and methodologies may be virtually unusable, or they will not provide relevant results (Bláha et al., 2009).

Among the more or less significant factors limiting the possibilities of using the GPH survey works, we generally include:

- urbanization and industrialization of surveyed sites;
- presence of line objects (fences, rails, power lines, etc.); asphalted areas, underground structures (various pipelines, tanks, etc.), or other metal scrap on a larger scale;
- low and high frequency electromagnetic interference;
- insufficient contrast of physical parameters within contaminated deposits, landfill fluids and unpolluted geological environment (rocks, water);

- significantly dropped groundwater table level and low groundwater flow rate;
- accessibility, morphology and trafficability of the terrain;
- required depth range and measurement detail;
- time consumption of some methods;
- insufficient depth of borehole (well), steel (to some extent PVC, as well) casing, deep-seated groundwater table, dry well;
- low gas permeability of the geological environment below the landfill or a landfill material;
- the landfill covering with various sealing foils and (separating) geotextiles;
- ambiguity of interpretation of the GPH measurements.

These limitations must be taken into account in the design as well as in the interpretation of the survey results in the areas of the environmental burdens.

The Tab. 2.1 presents a brief overview of the suitability of using selected methods of the applied geophysics in various fields of research work. It was compiled on the basis of many years of experience of solvers in various activities (not only) in the area of the EB (Gregor & Vybíral, 2015).

As a rule, the aim of the GPH exploration work is to specify the spatial structure of the rock environment, to determine the thickness of the coverings, the relief of the impermeable subsoil and the course of the failure zones, to determine the direction and rate of groundwater flow.

In the wider surroundings of most of the surveyed sites (objects), a relatively large number of the GPH works had been carried out in the past with different focus and scale of research. In terms of the requirements of the solution of the old EBs, the results of geoelectric methods were of particular interest. However, the vast majority of them were of regional character, or they were part of other (detailed) surveys and were mostly of marginal importance for the purposes of dealing with the EB.

From the point of view of the GPH works methodology, these regional works were interesting:

- Monitoring the Impact of Environmental Burdens on Geological Factors of the Environment in Selected Regions of the Western Carpathians (Vybíral et al., 2005);
- Use of Remote Sensing in Monitoring the Environmental Burdens on Geological Agents in Selected Regions of the Slovak Republic (Gregor et al., 2008).

In order to maintain the sequence of individual works and activities, the GPH's operations were divided into several stages:

- preparatory work – archival excerption, field reconnaissance;
- field work – stage 1 (CMD screening; draft of works in stage 2);
- field work – stage 2 (implementation of the additional GPH measurements at selected locations);
- preparation of partial final reports for surveyed location/object.

2.2.1 Preparatory work

A significant part of the preparatory work was focused in the detailed excerption of archived **documents**, their summarization, re-evaluation and possible reinterpretation. They were obtained from the archives of Geofond Bratislava, Department of Geophysical Research, SGIDŠ

Tab. 2.1 Suitability of the GPH methods applied to investigate the EB and their environmental impact

Suitability of applied geophysics methods at survey of the environmental burdens and their impact upon the environment	**CMD screening (DEMP)**	**Multicable (ERT)**	**Georadar (GPR)**	**Method SP**	**Method CBM (HG-variant)**	**Logging**	**Radiometry (SG/RVA)**
Localization of buried environmental burdens	🟩	🟩	🟩	☐	☐	▩	☐
Mapping of geological setting in horizontal pattern	▩	🟩	▩	🟧	🟧	☐	🟩
Mapping of geological setting in vertical pattern	🟩	🟩	▩	🟧	🟧	🟩	☐
Lithological composition and thickness of cover deposits	▩	🟩	▩	🟧	🟧	🟩	▩
Lithological composition and morphology of (impervious) subsoil	☐	🟩	☐	🟧	🟧	🟩	☐
HG regime in cover deposits	🟩	🟩	🟩	🟩	🟩	🟩	🟧
HG conditions of geological environ	☐	🟩	☐	▩	☐	🟩	🟧
Groundwater table level	☐	🟩	🟩	🟧	🟧	🟩	🟧
Direction and rate of groundwater flow	🟧	🟧	🟧	☐	🟩	🟩	🟧
Extent and character of contaminants spread	▩	🟩	▩	☐	🟧	🟩	🟧
Localization of subsurface technical facilities	▩	🟩	🟩	☐	☐	☐	🟧

🟩 suitable ▩ less suitable ☐ conditionally suitable 🟧 unsuitable

Map Server, professional publications, information sources on the Internet, etc. An important source of relevant information was also Enviroport, Envirofond, landfill register, old mining works register and old environmental burdens register.

Increased attention was paid to the **terrain reconnaissance**. In the first stage, the base documents were used along with available large scale orthophotomaps. Subsequently, in cooperation with the coordinators of individual sites, field reconnaissance was carried out, which served mainly to assess the possibility of realization of the field GPH, to get acquainted with the geological structure of the site and the content of the ecological burden itself.

In the terrain reconnaissance, directions and assumed lengths of profiles/routes for CMD screening were also proposed at individual sites.

2.2.2 Field work – stage 1

CMD screening – measurement of electromagnetic conductivity of local repositories (DEMP – Dipole Electromagnetic Profiling) – was the focal point of the 1st stage of the GPH field work. The CMD screening belongs to active GPH electromagnetic methods. The measuring devices used allow fast and operative measurement of resistivity, or conductivity from 3 to 14 depth levels at the same time, with a depth range of up to approx. 10 m (under optimum conditions up to ~ 15 m). The measurements are non-destructive, i.e. without interfering with the natural environment. It is not necessary to lay out the profiles, to drive-in the electrodes or to dig the probes and the measurements are carried out in the form of walks across the evaluated area (Fig. 2.1).

The measurement outputs indicate conductive bodies, resistivity division of rocks and deposits within the investigated area (sand, gravel, clay, ...). The conductive anomalies detect tectonic faults and failure zones that may indicate contaminated waterways at the site. The measurements also register metal objects, engineering networks (cables, pipelines, ...), various types of anthropogenic fillings, etc.

Fig. 2.1 Field measurements by CMD screening (source: www.gfinstruments.cz)

The basic CMD screening was carried out at all localities (objects) with the aim to determine the electromagnetic conductivity and susceptibility of local rocks, soils and deposits using a CMD-explorer (GFinstruments, s.r.o., Brno) at three depth levels (2.2 m, 4.2 m and 6.7 m) simultaneously. A measuring interval of 1 second was used.

The second device used (only for the Košice and Prešov regions) was the AEMP-14 Electromagnetic Profiler (NEMFIS, Moscow), enabling non-contact measurements at 14 depth levels simultaneously (only 2.2 m, 4.2 m and 6.7 m were entered for further processing) with a measuring step of 5 m.

The measured quantity was the apparent resistivity (apparent specific conductivity) and the "in-phase" component, which is proportional to the magnetic susceptibility of local rocks and deposits.

Each measurement was recorded along with the position of the measured point using a GPS receiver. The distance of the profiles – according to the possibilities of realization and availability of the terrain – was in the range up to 50 m and the measuring step up to 5 m. A separate **assessment report** was subsequently prepared for each site/object (group of close-lying objects) with an interpretation of the measurements by the CMD screening, including a proposal for further GPH work at the site/object.

2.2.3 Field work – stage 2

Within this stage, geophysical profiles were identified and surveyed in selected locations according to the conclusions of the evaluation reports and the measurements were carried out using one of the other methods of the geological task project: multicable (ERT), georadar (GPR), spontaneous polarization (SP), charged-body method – hydrogeological variant (CBM – HG), gamma spectrometry (SG), emanation measurements (RVA – ^{222}Rn volume activity) and logging in selected boreholes.

Prior to the GPH works were carried out, the GPH profiles were laid out (the routes were cut to the necessary extent if necessary), with pins staggered by 50 m. Using the GPS receiver (accuracy up to 1 m), the survey profiles were then geodetically surveyed. Their number at a site (object), length and distance between profiles were determined individually as needed to achieve the set goals of the geological task. In setting the profiles, in cooperation with the site coordinator and the responsible geological task solver, the results were based mainly on the results of the CMD screening, but also on other available knowledge about the site setting.

The Multi-Cable Method (ERT – Electrical Resistance Tomography) is currently one of the most widely used geoelectric methods in environmental studies. It is a system of complex resistance measurement with a larger number of electrodes. The distance between the electrodes is determined depending on the detail and the desired depth range. The electrodes serve alternately as the source and receiver ones.

Considering the fact that the measurements are carried out by means of a series of electrodes configured with small spacing (max. approx. 5.8 m) and by computer-controlled addressing of current transmission and voltage reception, it is possible to obtain a relatively detailed picture of vertical distribution of apparent resistivity in vertical section along the measured profile.

The field measurements were performed using the ARES geoelectric apparatus (GFinstruments, s.r.o., Brno) and multielectrode sections with N * 8 electrodes (Fig. 2.2). The electrode spacing was chosen in the range of 2.0 – 5.8 m with a depth reach of up to 50 m.

Subsequent computer processing allows the measured data to be transformed into a set of real values of resistivity and through them to obtain a picture of the real structure of the rock environment along the measured profile.

RES2DINV (Company GEOTOMO SOFTWARE, Malaysia – a standard 2D inversion application) software was used to interpret resistivity images, which assumes that the apparent resistances change only in the profile direction (X axis) and depth (Z axis). The programme generates a model whose calculated values are as close as possible to the measured values. It uses the smoothing method to solve the system of linear equations.

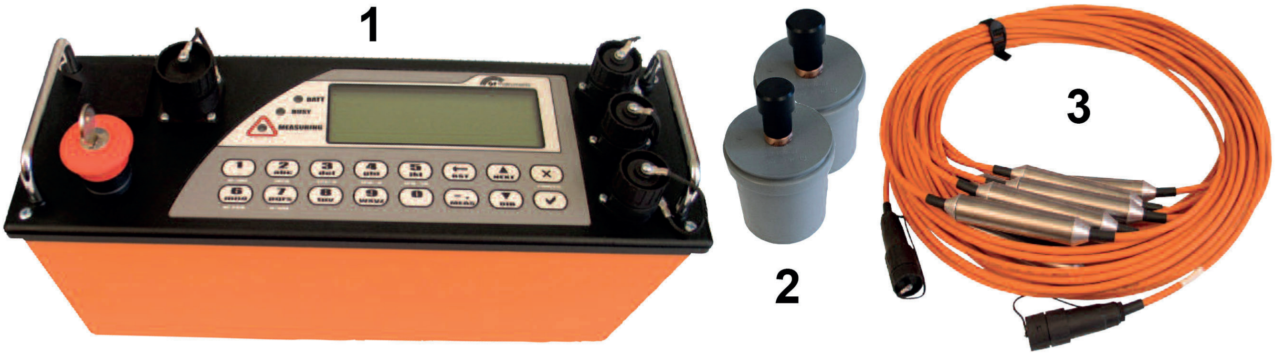


Fig. 2.2 ARES Geoelectric Apparatus (1); non-polarizable electrodes (2); active multi-electrode cable (3) (source: www.gfinstruments.cz)

Georadar (GPR – Ground Penetrating Radar) utilizes the reflection of high-frequency electromagnetic waves transmitted and received by the measuring apparatus from the interfaces of various subsurface natural/anthropogenic layers and interfaces with different conductivity and permittivity (Fig. 2.3). By the georadar it is possible to study the geological environment relatively quickly and effectively to the depth of the first units (up to tens of meters).

For the georadar measurements, the depth range and resolution of the method are determined by the use of antennas with variably radiated frequency. Measurements on the old EBs used 500 MHz and 350 MHz antennas with depth range of 2.5 – 3 m at the first (resolution > 5 cm), or 5 – 6 m for the second antenna (resolution > 20 cm).

In the case of shallow auriferous conductive layers, or any layers with high conductivity, the depth reach of the georadar is limited by the depth of the conductive layer. The antenna was selected according to the particular situation along the measured profile and the requirements for the size of the details to be monitored.

Fig. 2.3 Georadar measurement on designated geophysical profiles

The **spontaneous polarization method** (SP) is one of the oldest GPH methods. It investigates local electrochemical fields arising from groundwater flow (hydraulic conductivity potentials), ion movement on contact of various mineralized/contaminated groundwaters (diffusion potentials), or on contact of groundwater and ore minerals (oxidation-reduction potentials). Elevated SP values may also have anthropogenic origin, e.g. corrosion of various pipelines, electrical noise (stray currents, electrification, railways, etc.).

The potential difference in the electric field between two points at the surface is measured. The method is used to indicate various types of leaks and escapes, for detailed measurements in the inspection of sealing walls, etc.

The field measurements were carried out using the ARES geoelectric apparatus (GFinstruments, s.r.o., Brno) and non-polarizable electrodes (Fig. 2.2) in a potential configuration. The use and scope of the SP measurements were determined individually according to the possibilities and conditions at a particular site/object.

The **charged-body method** (CBM) is a special variant of the SP method. It is designed to monitor the direction and speed of groundwater flow around the borehole (well), the course of underground streams, leakage of sealing foils below a landfill, etc. One of the current electrodes is placed in the well below the water surface, whose conductivity is increased by adding a salt. The measurements at the surface can then monitor the rate and direction of movement of the salt-enriched medium.

The use of the CBM method was possible only under favourable conditions and was used selectively also according to the possibilities of its implementation at a specific site (object). The method has a relatively low depth reach and its use is not possible in environments with increased conductivity of the geological environment (clays, clays, tuffs, heavily mineralized groundwater, etc.) and its practical use is therefore considerably limited. Good results can be obtained e.g. in gravel-sand sediments with a small thickness of coverings.

The field measurements were performed using the MRS-256 geoelectric apparatus (Fig. 2.4), or by ARES (Fig. 2.2). In the vicinity of each borehole 8 radial profiles with a length of 15 m were laid out, on which the sensing (potential) electrodes were grounded in steps of 1 m. The artificial electric field was created by current electrodes placed in the borehole and in the so-called “infinite” position (approx. 140 m from the borehole). Changes in resistance ratios were observed within a few (to tens) days of the start of the addition of salt to groundwater.

Logging (geophysical measurements in a borehole) is probably the largest set of geophysical methods and methodologies, the results of which provide detailed relevant information on the physical properties of the geological environment along the well axis: lithology, radioactivity, porosity and pore fill, electrical resistance, polarization, magnetic susceptibility, density, technical condition, course of the borehole axis, temperature, inflows and direction of water flow in the borehole and many other parameters.

Fig. 2.4 Geoelectric apparatus MRS-256 (source: www.gfinstruments.cz)

The logging works were carried out in new (or other available) survey boreholes: cavernometry (CM), thermometry (TM, 2 measurements), resistivimetry (RM), 5 measurements of RM after dilution, gamma-carotage (GC) and electro-carotage if possible).

The logging results were processed, visualized and interpreted at a scale of 1: 100 and a separate evaluation report was prepared for each borehole (group of boreholes). An example of a logging apparatus is shown in Fig. 2.5.

Fig. 2.5 Logging equipment for borehole measurements (source: www.koral.sk)

Pedestrian **gamma spectrometry** (SG) is mainly used in mineral exploration, geological mapping, environmental radioactivity monitoring (including indicative determination of natural and/or artificial radionuclide concentrations at various landfills and repositories), assessment of radioactivity of building materials, etc. The most important natural sources of rock gamma radiation are potassium (K), uranium (U) and thorium (Th). The artificial radionuclides then e.g. ^{137}Cs, which entered the natural environment after the Chernobyl nuclear power plant accident in 1986.

In order to determine the basic parameters of natural radioactivity (potassium concentration K, equivalent uranium eU, equivalent thorium eTh, total natural

Fig. 2.6 Gamma spectrometer GAMMA Surveyor (source: www.gfinstruments.cz)

radioactivity eUt and dose rate of gamma radiation), gamma spectrometry spot measurements were performed in the immediate vicinity and also in the area of the EBs in a configuration of 5 points in the area of EB and 5 points outside the building of EB. A GAMMA Surveyor (GFinstruments, s.r.o., Brno) and a measurement time of 3 minutes were used (Fig. 2.6).

Emanation (radon) exploration is mainly used for geological mapping, searching for tectonic lines, assessing radioactivity of the environment (e.g. determining the radon risk of a building plot), searching for energy resources (uranium), assessing the radioactivity of building materials, etc.

Simultaneously and at the same positions as the natural radioactivity (SG) parameters were measured, soil air was extracted from a depth of up to 0.8 m to determine radon volume activity (RVA). RVA measurements were performed with a metrologically verified and calibrated LUK-4 measuring instrument (manufactured by Ing. J. Plch, Prague) with 125 ml Lucas type (LC) scintillation chambers (Fig. 2.7).

Fig. 2.7 Apparatus LUK-4 and Lucas Chamber volume 125 and 600 ml (source: www.geology.sk)

All the ground documents and data (measured and interpreted), obtained during the solution of the geological task in question (Kordík & Slaninka et al., 2015), are stored in the approved structure and physical content of individual sites, types of work and methods on the SGIDŠ data server and archived on optical media (more than 13,000 files; 15x DVD-R).

2.3 Overview and results of realized work

Detailed knowledge of the geological structure of the investigated EB area helps to identify potential impacts and possibly the spread of contamination. Applied geophysics can help in defining the extent of coverings, determining the depth of the (impermeable) subsoil, determining the horizontal (areal) and vertical character and delimiting of the lithological complexes, in mapping the failure zones, etc.

The areal (to some extent also spatial) extent of individual lithotypes was surveyed by profile measurements, where the GPH methods were applied, mainly in which mapped rocks and deposits showed sufficiently contrasting physical properties (specific electrical resistance, magnetic susceptibility, but also natural radioactivity) against uncontaminated environment.

Differentiation of lithotypes is important e.g. also in differentiation of their hydrogeological function. Impermeable deposits with a predominant clay component are electrically conductive due to the bound water and thus have lower resistances. Coarse-grained sediments with high inter-granular permeability are characterized by higher resistances unless they saturated with mineralized/contaminated water.

2.3.1 CMD screening

The **CMD screening** (DEMP) was used at all 161 solved sites/objects in the first phase of the GPH works (altogether approx. 1,088 km of routes), which aimed to delineate local rocks and deposits according to their electromagnetic properties.

However, an important limiting factor in the performance of this type of exploratory work is urbanization and industrialization, and more or less significant electromagnetic interference. At several localities, this led to the situation that the methods of geoelectric survey (multicable, georadar, SP method, CBM method) were not recommended at the next stage, because the relevant results could not be expected.

However, this fact can be considered rather positive because there was no waste of funds that could – to some extent – be used at other, more appropriate locations/objects.

Based on the CMD screening results, environments with reduced apparent resistivity corresponding to clay-type rocks, deluvial sediments, landfills with an increased proportion of clay fraction, etc. were indicated. It was often possible to observe mostly hidden old oxbows and meanders of watercourses (Fig. 2.8). Low resistances reflect both anthropogenic effects (various pipelines, utility networks, etc.), but also contamination of deposits with increased/high content of decomposed petroleum substances.

Higher apparent resistances set aside areas with a lower clay content and an increase in the proportion of gravel and sand, or landfill material with increased specific resistance (rubble, construction waste, etc.).

Since it was simultaneously mapped for three different depth levels, the thickness of the mapped geoelectric layers can also be determined from the visualized outputs to some extent.

It was possible to identify various metal materials in the examined areas, or in landfill material, based on the results of the in-phase component measurements, which is proportional to the magnetic susceptibility of local rocks and deposits. Such material is reflected in the visualized measurement results by expressing higher values (Gluch in Kordík & Slaninka et al., 2015).

In a smaller number of objects, where the electromagnetic properties of the surveyed geological environment did not show the necessary contrast, or they were affected to varying extents by civilization interference, the results of CMD screening were not sufficiently demonstrable, and – based on the principle of this method they could not be representative.

In general, it can be stated that better readable results of the CMD screening (but also the other GPH works) were achieved at most sites (objects) in case of their processing in the form of maps of the measured component. Measurement outputs presented in the form of individual profiles had a slightly lower level of information.

2.3.2 Multicabel

The multicable (ERT) method is used for geoelectric research along marked and surveyed GPH profiles. The presentation of results in the form of inverse resistance models and geophysical-geologically interpreted sections is currently the standard for detailed work in the explored areas (Fig. 2.9).

One of the basic problems of all geoelectric methods is the ambiguity of

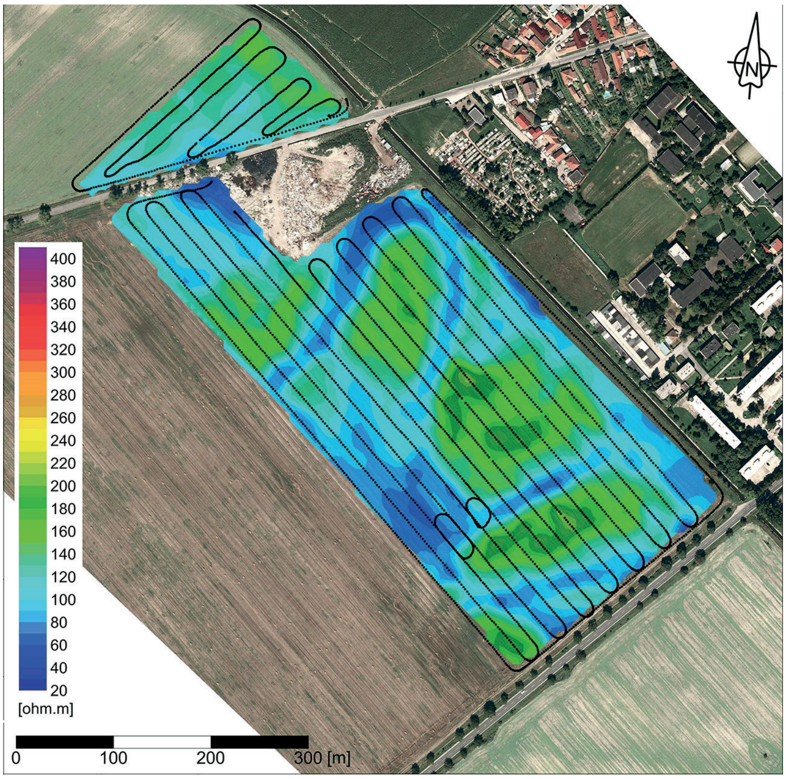


Fig. 2.8 CMD screening results – locality 108 Zlaté Klasy (apparent resistivity [ohm.m] for effective depth range 4.2 m; CMD measurement paths) (compiled by Company Sensor, spol. s.r.o. Bratislava, modified by Gluch & Zeman, 2019)

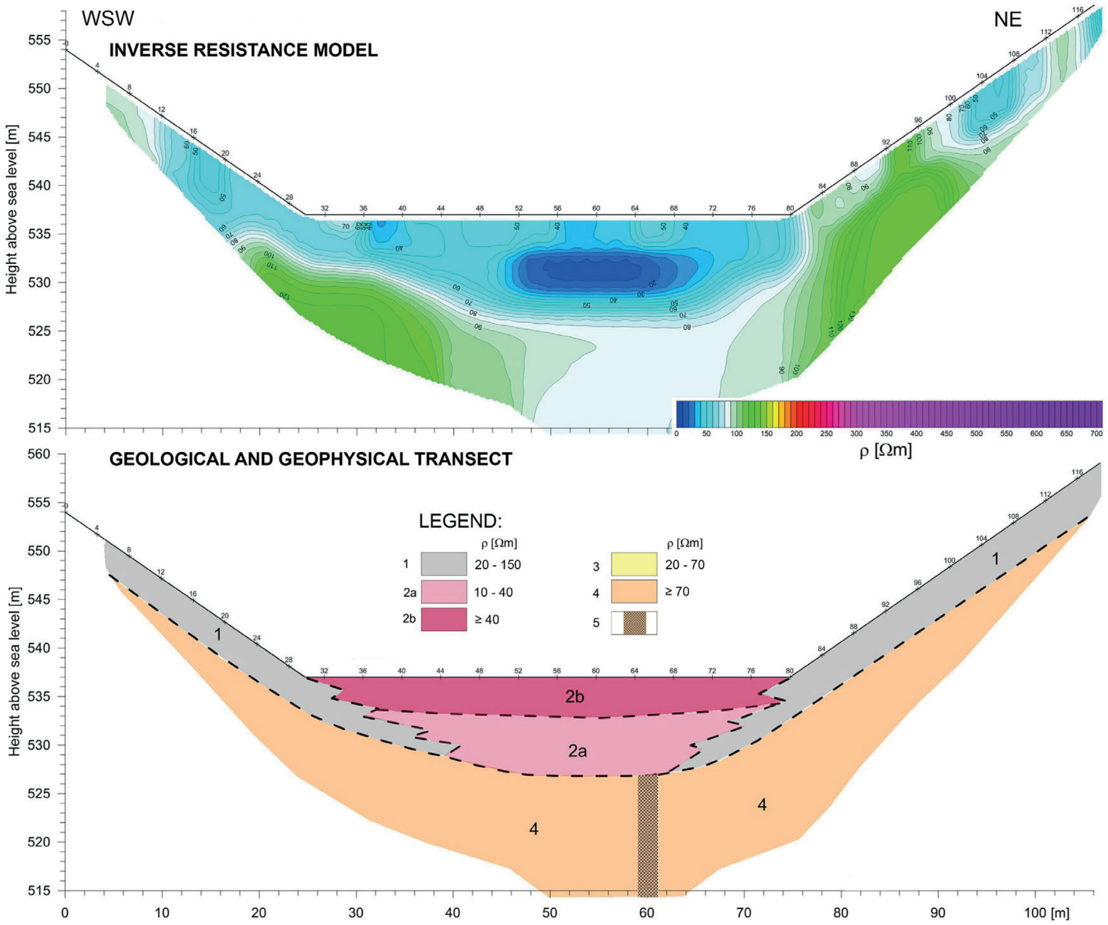


Fig. 2.9 Multicable measurement results – locality 51 Medzibrodie nad Oravou. Legend: 1: surface layer, eluvial-deluvial sediments; 2a: anthropogenic fill, prevalence of municipal waste; 2b: anthropogenic fill, predominance of coarse-grained component; 3: predominance of claystone; 4: limestone, or sandstone, siltstone; 5: failure zone/tectonics (compiled by Company BHF Environmental, spol. s.r.o. Bratislava, modified by Gluch & Zeman, 2019)

interpretation of measurement results. In general, the so-called principle of equivalence, but also anisotropy of the geological environment are significant, so the computer-generated model is the only one possible solution. The refinement of the geophysical-geological interpretation can be achieved by supplementary data obtained e.g. from logging results in available supporting boreholes.

In spite of the above, the results obtained from the ERT measurements sufficiently illustrate the suitability and justification of their use – detailed and relevant information on the geometry and stratigraphy of rocks and deposits on the premises of objects/locations up to the first tens of meters depth. However, the multicable has found application e.g. even with the unexpected detection of unknown subsurface spaces (Gluch in Kordík & Slaninka et al., 2015).

2.3.3 Georadar

The georadar uses a different principle compared to a multi-cable, but the measurement outputs in a similar way – but with a significantly higher resolution (depending on the antenna transmitting/receiving frequency) – indicate interfaces with different conductivity and permittivity (Fig. 2.10).

The advantages of georadar are simplicity and speed of measurement, high resolution and relatively simple

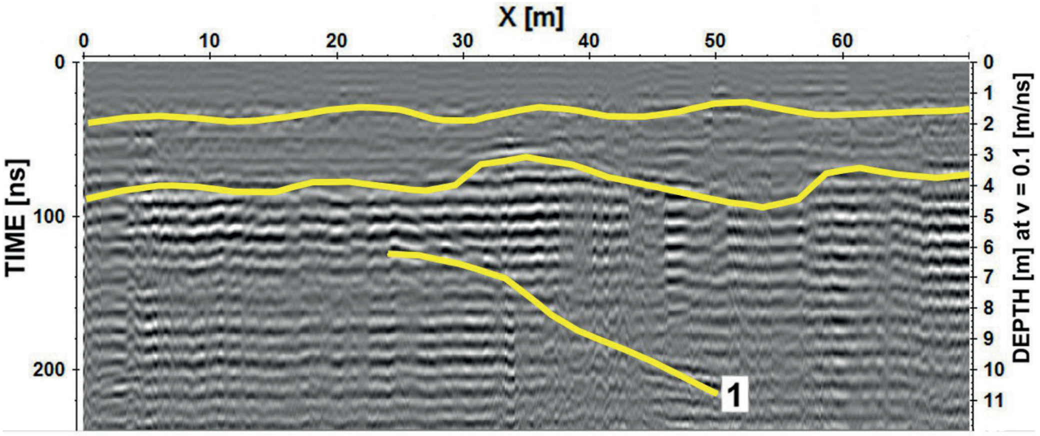


Fig. 2.10 Results of georadar measurements – locality 71 Lučenec (1: interpreted interface) (compiled by Company Sensor, spol. s.r.o. Bratislava, modified by Gluch & Zeman, 2019)

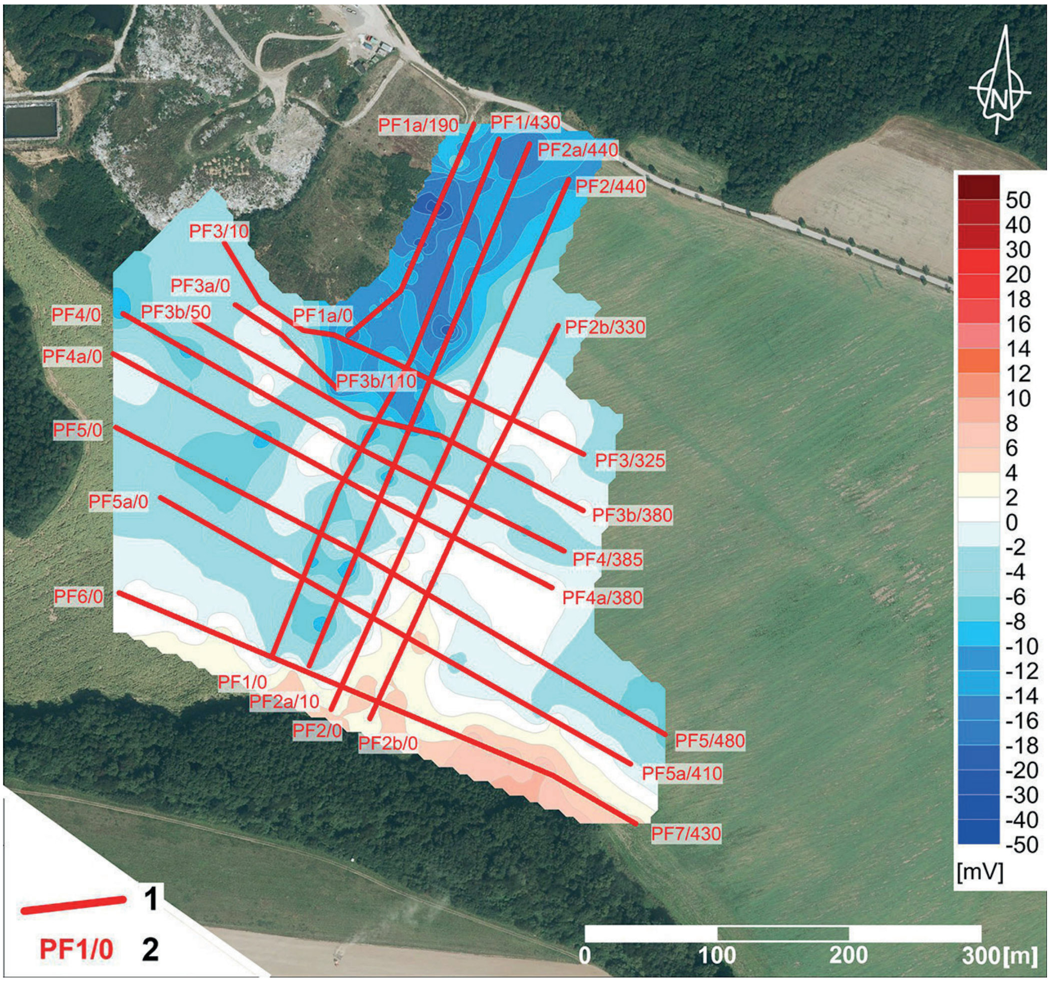


Fig. 2.11 Measurement results by the SP method – locality 85 Bojná (1: measured profile; 2: profile number and length) (compiled by Company DEKONTA Slovensko, spol. s.r.o. Bratislava, modified by Gluch & Zeman, 2019)

interpretation. The limiting factors are in particular: the transmitted frequency, determining the resolution of details, specific conductivity of geological environment, but also water content, density of rocks and deposits, etc. A necessary assumption is a sufficiently different permittivity, or specific conductivity of individual lithotypes, but also a reasonably large reflective surface of explored structures.

Despite the fact that the georadar was used only at 5 sites/objects, it confirmed its justification. Combination with another suitable GPH method, e.g. using the multi-cable method (if allowed by environmental parameters and measurement conditions) and ideally with logging results on the supporting boreholes is the optimum utilisation of the georadar.

2.3.4 Spontaneous polarization method

The SP method could be used only at 25 localities/objects in a total of 8,770 measured points. This method measures the potential difference between two points on the profile, or within the exploration area, generated by various local electrochemical fields. The advantage of the SP method is its simplicity and speed of measurement. The limiting factor is the presence of various disturbances caused mainly by civilization factors. The possibilities of its use in urbanized areas on a larger scale are thus significantly limited. The negative SP values indicate the areas of possible ground/landfill contamination. From the results of measurements it is possible to determine the spatial extent and to some extent also the level of contamination

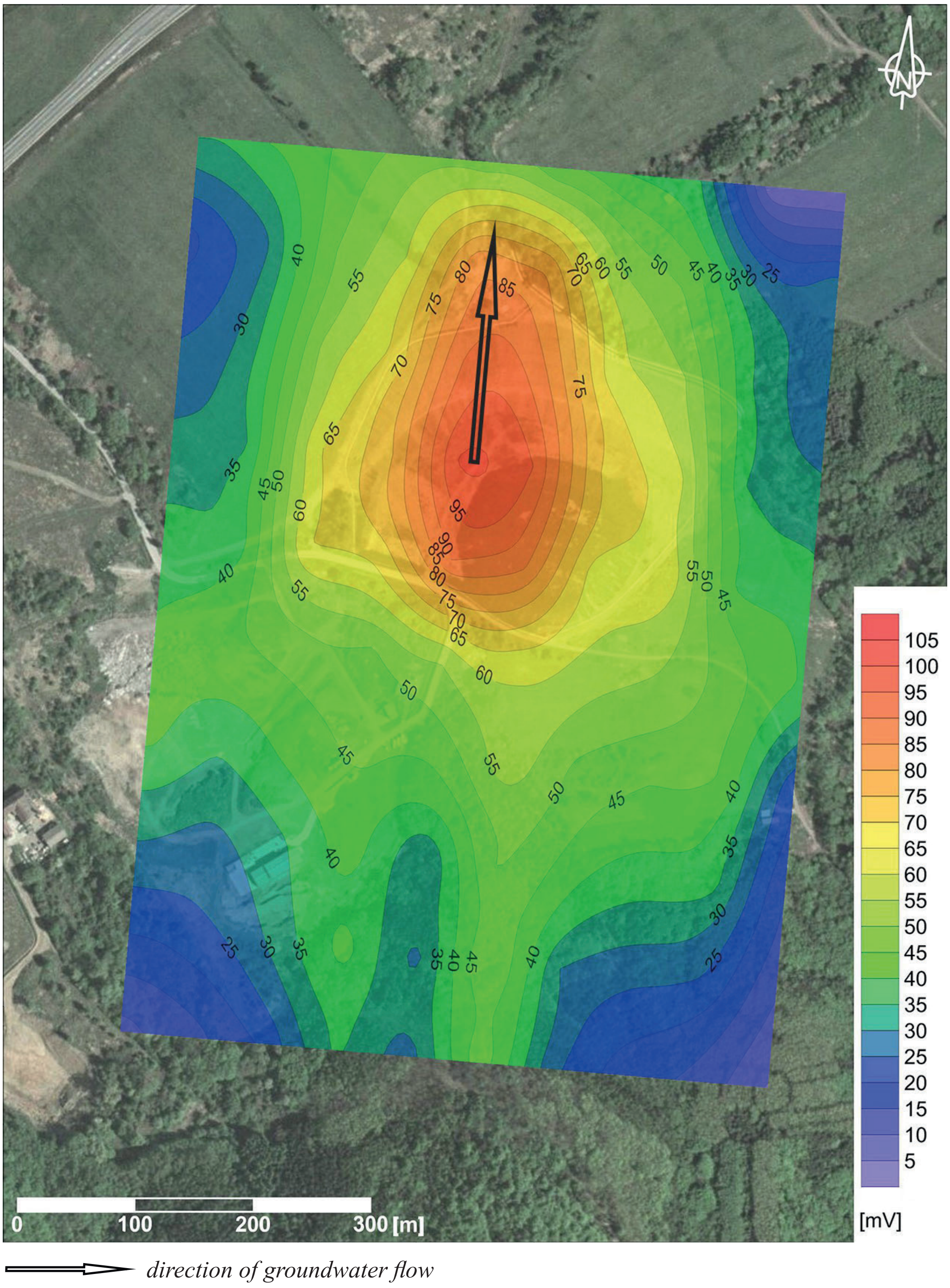


Fig. 2.12 Charged-body method measurement results – locality 168 Žiar nad Hronom (compiled by Company Sensor, spol. s.r.o. Bratislava, modified Gluch & Zeman, 2019)

of the environment around the environmental burden (Fig. 2.11). Under specific conditions, it is also possible to determine the direction of groundwater flow from the SP measurements.

Despite the fact that the SP method could only be used on a relatively small number of sites, its merits and benefits are undeniable.

2.3.5 Charged-body method

Due to the very specific conditions of the possibility of realization of the CBM (HG variant) method, it could be used basically only in 7 localities. From the results of time-consuming measurements it was possible to determine the direction and speed of the groundwater flow. The limiting factors are mainly: relatively low effective depth reach, impossibility to use the CBM method in a rock environment with high conductivity, depth of the groundwater level (decimetres up to the first meter) and last but not least the longevity of measurements in the order of tens of days, depending upon the groundwater flow rate. When selecting suitable objects (boreholes, wells), the CBM measurement results provide reliable data (Fig. 2.12).

The results of the measurements of the charged body method at the site (Fig. 2.12) confirmed the propagation of the electric field in the geological environment, and this field was deformed. The deformation was caused by the spread of contaminated groundwater in the direction shown by the arrow.

2.3.6 Logging

The geophysical measurements in a borehole (logging) are probably the most extensive set of methods and methodologies, the results of which give detailed and relevant information about the physical properties of the geological environment along the well axis. The limiting factors of logging work are mainly too low depth of the well, steel casing of the borehole (to some extent also PVC), deep groundwater table level or dry well, etc. One of the limitations in the implementation of this project was the fact that a significant number of boreholes were drilled only during the first half of 2015, but the logging (part of the GPH works) was contractually concluded in early January 2015. The logging outputs allowed to separate lithological boundaries of rocks caught by borehole, hydrogeological aquifers and aquitards, places of inflows and losses in the borehole, hydraulic conductivity values, temperature and specific resistance of drilling mud, etc. (Fig. 2.13).

2.3.7 Radiometric methods

The radiometric methods – gamma spectrometry (SG) and radon survey (RVA) – were used at all 161 sites in a number of 10 points SG and RVA in the vicinity, but also directly in the EB object. Results of the radiometric determination of concentrations of natural radionuclides "in situ" by measurements of SG, or the radon volume activity in the soil air indicate their very good mapping

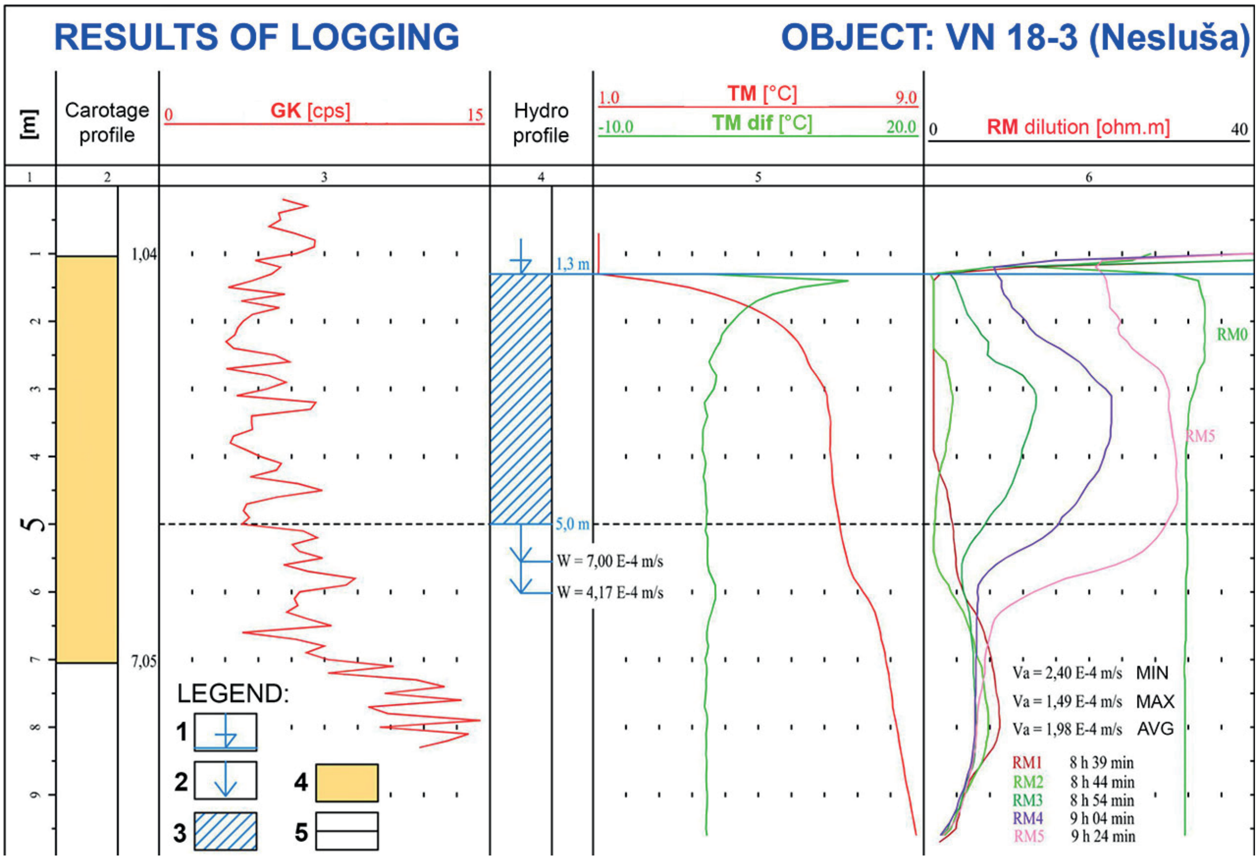
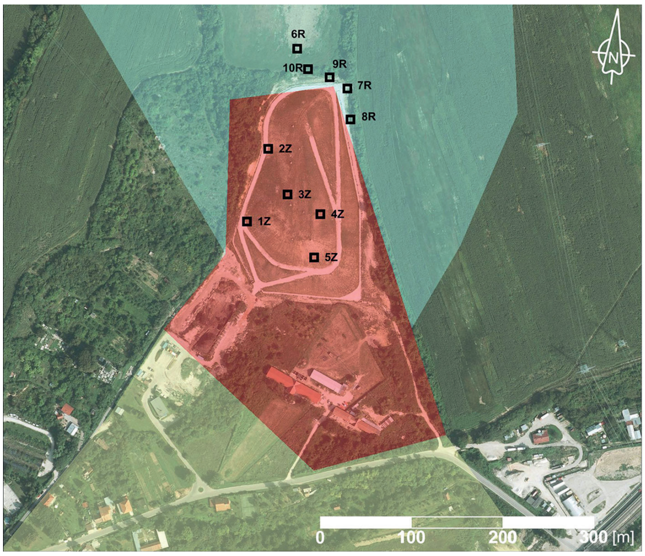


Fig. 2.13 Logging results – location 18 Nesluša. Legend – 1: water level; 2: vertical movement of water; 3: filtration of water over time; 4: permeable rocks, collectors; 5: rock interface; GK: gamma logging [cps]; TM: thermometry [°C]; RM: resistivimetry [ohm.m]; W: vertical rate [m.s^{-1}]; Va: hydraulic conductivity coefficient [m.s^{-1}] (compiled by Company KORAL, spol. s.r.o. Spišská Nová Ves, modified by Gluch & Zeman, 2019)

capability, which was also confirmed by the results of measurements at several locations/objects. Significantly increased levels of equivalent uranium (eU = 9.0 – 12.3 ppm), which correspond to increased (eU ≥ 4.0 ppm) to high (eU ≥ 10.0 ppm) natural radioactivity of the rock environment, were identified, e.g. in clay and loess clays at 21 Nové Mesto nad Váhom – KO Mnešice – Tušková landfill (Gluch in Kordík & Slaninka et al., 2015; Fig. 2.14).



Point	K [%]	eU [ppm]	eTh [ppm]	eUt [ur]	Da [nGy.h^{-1}]	OAR [kBq.m^{-3}]
1Z	1.1	12.1	8.6	19.3	104.6	12
2Z	0.9	11.4	7.8	17.8	96.6	12
3Z	1.1	10.8	6.9	17.4	93.8	15
4Z	1.5	12.3	7.6	20.2	109.0	16
5Z	1.1	11.7	4.5	17.0	92.4	14
6R	0.8	10.0	1.2	12.8	70.5	11
7R	0.9	9.7	1.9	13.2	72.0	15
8R	1.0	10.2	1.6	13.8	75.4	11
9R	0.9	9.4	1.0	12.5	68.4	11
10R	0.9	9.0	1.3	12.1	66.1	7
Limits	**≥ 2.0**	**≥ 4.0**	**≥ 12.0**	**≥ 17.0**	**≥ 80.0**	**≥ 20**

LEGEND:

1 ◘1Z

Conceptual model:

2 🟥 3 🟨 4 🟦

Fig. 2.14 Radiometric survey results – locality 21 Nové Mesto nad Váhom. 1: measurement point SG and RVA; 2: source zone (Z); 3: indication zone; 4: reference zone (R) (compiled by Company BHF Environmental, spol. s.r.o. Bratislava, modified by Gluch & Zeman, 2019)

Source zone represents the source(s) of the pollution, in this case environmental burden; indicative zone denotes the area where the pollution occurs/could occur from the EB; the reference zone delineates the territory not affected by the EB (natural conditions).

High concentrations of soil radon were found e.g. in the area of the EB 117 Sliač (Kordík & Slaninka et al., 2015). All 10 points, measured in both the reference and source areas (RVA = 30 – 208 kBq.m^{-3}), are bound to the failure zone, overlain by polymictic coarse and medium-grained, sand-covered gravel. Pursuant to Annex no. 6 of the Decree of the Ministry of Health of the Slovak Republic no. 528/2007, which lays down the details of the requirements for limiting the exposure from natural radiation, the object falls under high radon risk.

An overview of field geophysical measurements carried out in the course of the project is shown in Tab. 2.2.

2.3.8 Atmogeochemistry

The atmogeochemical measurements were not part of the design work and were not carried out experimentally until the second half of 2015 at several selected locations. The advantage of atmogeochemistry is the rapid and sufficiently accurate determination of the detected gas concentrations (depending on the equipment of the detectors) in the landfill air. The limiting factors are mainly the thickness of the overburden, the high groundwater level and the use of sealing foils for landfill reclamation.

The Dräger X-am 7000 measuring unit (of the Company Drägerwerk AG & Co. KGaA) was used for measurements, equipped with detectors for the determination of CH_4, CO_2 and O_2 content [vol. %], which was connected to the sampling probe (Fe-pipe, ϕ = 12 mm, length approx. 1 m) via silicone tubing through a washer (to prevent water from entering the instrument). The landfill air was continuously pumped by an integrated pump from a depth of 70 – 80 cm and subsequently "in situ" analyzed by the evaluation unit.

The measured or the support points on the profiles/routes were geodetically levelled by the professional GPS receiver Trimble Geo 7X (Trimble Navigation Limited, USA); the levelling accuracy reached about 10 cm in the X and Y directions, up to 25 cm in the Z axis. The assay results were then processed and visualized in the SURFER

Tab. 2.2: Overview of realized geophysical field measurements

Region	**CMD [m]**	**SP [points]**	**ERT [m]**	**GPR [m]**	**SG [points]**	**RVA [points]**	**Karotáž [m]**
Bratislava and Trnava	222,683	1,775	29,909		320	320	
Banská Bystrica	231,954	1,768	25,673		350	350	285.3
Košice and Prešov	180,709	2,176	29,043		400	400	211.2
Nitra	200,121	1,520	23,415		270	270	310.9
Trenčín and Žilina	252,249	1,531	23,353		290	290	292.8

software application environment (GoldenSoftware Inc, USA; Fig. 2.15).

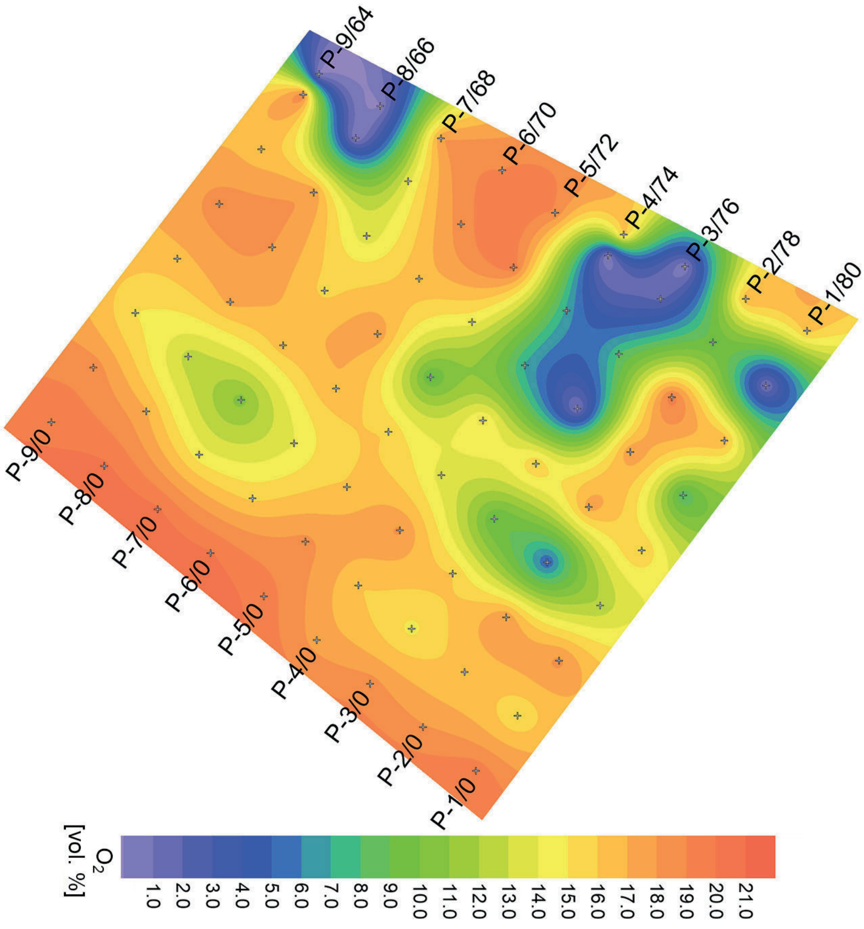


Fig. 2.15 Atmogeochemistry results – location 144 Spišská Belá (O_2 concentration [vol. %]) (compiled by Gluch & Zeman, 2019)

At the locality 144 Spišská Belá the atmogeochemistry was realized at a distance of about 120 m southeast of the old reclaimed landfill in a regular network of measured points (10 x 10 m). The results of the "in-situ" determination of oxygen concentrations in landfill air are documented in Fig. 15.2.

The measurements confirmed good detection capabilities of the measuring apparatus for the above mentioned (landfill) gases. Based on the acquired knowledge, it was recommended in the future to purchase a Smart PID sensor, which would enable to significantly increase the usability of "in situ" atmospheric chemistry determinations, e.g. in areas of various chemical plants and treatment plants, fuel storage and handling, etc.

2.4 Conclusions

The environmental burden is defined in terms of the Geological Act (Act 569/2007 Coll.) as contamination of the area caused by human activity, which represents a serious risk to human health or the rock environment, groundwater and soil. The solution of the issue of environmental burdens came to the attention especially in the early 1990s in connection with their elimination in the territories abandoned by the former Soviet Army troops. At present, the environmental burdens and information on their location and potential risks are recorded in the Information System of Environmental Burdens (ISEZ), which is part of the public administration information system.

The output of the geological task, the geophysical part of which is the subject of this article, is a set of geological-geophysical data and information used in the creation and implementation of an optimal monitoring system of the selected environmental burdens in the Slovak Republic.

The use of the applied geophysics methods has been limited in many cases by civilization influences to various extents, but in most cases the structure of the GPH exploration works has been operatively modified so that the requirements, objectives and goals of the project were met as far as possible.

Based on the analysis of the described GPH works, including a critical assessment of possible adverse impacts on these activities, it can be concluded that the project-designed and realized complex of the GPH measurements proved to be suitable, rationally designed and to some extent also generally applicable in monitoring (not only) of the old EBs.

In similarly structured exploratory projects we recommend for the future:

- in the methodology of the GPH survey to use so-called complex profiles on which all project-specified GPH methods and methodologies would be implemented, including the use of the logging results from suitably situated supporting boreholes;
- to include the atmospheric chemistry in a standard set of monitoring works (at least on the complex profiles);
- in justified cases, to include works the profile and/or area magnetometry in the range of the GPH (at least on complex profiles);
- to increase the share of multi-cable (ERT) and/or georadar (GPR) measurements in the EBs;
- to make more extensive use of radiometric measurements (SG and RVA).

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3. Application of Remote Sensing in Monitoring of Environmental Burdens

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Abstract: In the Slovak Republic, according to the Geological Act in force, environmental burden (EB) is defined as pollution of a territory caused by human activity, which represents a serious risk to human health or the rock environment, groundwater and soil with the exception of environmental damage. It is a wide range of areas contaminated by industrial, military, mining, transport and agricultural activities, but also by improper waste management. Old environmental burdens cover a wide range of problems such as municipal waste dumps, industrial waste, tailings ponds, heaps, abandoned and active industrial buildings, but also line constructions and others that can cause soil and water pollution and contamination.

The assessment of the negative effects of the EB on the basis of information from remote sensing is possible by comparing images from several time periods focused on the territory of EB and its immediate surroundings, especially in the area of the interaction zone. Changes can be monitored by direct and indirect spatial symptoms on vegetation, soil, snow cover, as well as on the condition of roads, buildings, technology, etc. In the Slovak Republic, this issue was addressed by the State Geological Institute of Dionýz Štúr in Bratislava (Monitoring of Selected Environmental Burdens in the Territory of the SR, Zvara et al., 2015a; Kordík & Slaninka et al., 2015) and Section of Geology and Natural Resources of the Ministry of the Environment, Zvara et al., 2015b) and other ongoing stages of the solution of this issue (Survey of Selected Environmental Burdens in the Territory of the Slovak Republic, stages I and II, 2019).

In solving these tasks, a methodical procedure was proposed, applied to type localities, optimized for efficient use and generalized for the investigation of sites of a similar nature. The results of the use of remote sensing in the monitoring of environmental burden point to a fast, relatively accessible and highly accurate spatial assessment of the impact of the EB on their surroundings as well as the possibility of monitoring the history of EB with the potential to predict further development of the situation.

Keywords: remote sensing, high resolution multispectral satellite imagery, airborne imagery, monitoring of environmental burdens

3.1 Introduction

From the point of view of science-based disciplines the remote sensing is a set of methods dealing with the collection of data on landscape without direct physical contact with it, data processing and data interpretation. The basic physical phenomenon on which the remote sensing is based is the interaction of solar electromagnetic radiation with the ground components, while part of the incident radiation is absorbed by the ground objects, part is further penetrating and some is reflected back.

The absorbed radiation from the sun is the most important energy source of physical, chemical and biological processes in the landscape. At a particular point in time, data on objects in a landscape are obtained by measuring the reflected intensity (in the visible, near and middle infrared part of the spectrum), or radiated intensity of radiation (in the far infrared part of the spectrum). Information on landscape is obtained by processing and interpreting remote sensing data, using only certain parts of the spectrum (so-called atmospheric windows) that are least affected by atmospheric disturbances.

Old environmental burdens cover a wide range of problems such as municipal and industrial waste dumps, tailings ponds, heaps, abandoned and active farm buildings, line and other structures that can cause soil and groundwater pollution and contamination. The evaluation of the negative effect of EB on the basis of information from remote sensing is possible by observing its effects directly in the area of the interaction zone.

3.2 Methodology

One of the key points of remote sensing application in the environment is to carry out a comprehensive survey of the landscape from above, to record newly acquired data, to document both visually visible and covered environmental burdens and their negative impact on the environment. The use of the remote sensing itself can, under certain circumstances, be a very efficient, relatively fast, high-quality, comprehensive and non-destructive way of obtaining this information.

The acquired findings have to be verified for correct interpretation by field and laboratory work (sampling, evaluation of soil quality, groundwater), modelling (erosion-accumulation processes, prevailing wind directions, shading of the terrain, etc.).

It is important to observe a set of spatial symptoms at monitoring of covered environmental burdens and to assess their environmental impact:

– **Positive spatial vegetation symptom**: Soil components found in most covered landfills cause their chemical composition – mainly due to phosphates, nitrates and other substances to differ from the surrounding soil environment. In this environment, especially if it is rich in sand, water is impounded for a longer time, which makes it different in colour, height and density of the crops

growing above the load and in its impact on the environment. After long-lasting rains, these areas will differ in colour, especially in spring and autumn, from the surrounding environment, so-called **humidity symptom**;
- **Negative spatial vegetation symptom**: At covered sites with construction debris, industrial or mining waste, the plants do not reach the height of the surrounding vegetation, they ripen earlier and therefore have a lighter coloration than the surrounding matching crops. During a prolonged dry season such an area is dried out (**a symptom of drought**).

Other, less commonly used are: **soil symptom**, observable mainly in spring and autumn as a change in soil colour shade of the covered EB material after ploughing, and **snow symptom**, observable on winter and spring days when the temperature of decomposing organic matter in anthropogenic sediments is also several degrees higher, which is reflected on the surface by faster snow melting.

The intensity of reflected and emitted radiation is dependent on the electromagnetic properties of the substance and is related to its immediate physical state. By analyzing spectral characteristics, it is possible not only to identify various objects in the landscape (e.g. meadow, house, road, pond, etc.) but also to obtain information about their current state (e.g. humidity, admixture, height, age, density, etc.).

The sensing devices are located on aircraft or satellites. The data are recorded by cameras on film material or are scanned by scanners and transmitted in digital form to the ground receiving station immediately.

The scanning of the earth's surface is performed in different spectral bands and in different spatial resolution. Black-and-white (panchromatic) data are usually more detailed, with aerial images using analogue or digital colour RGB images; most recently with infrared (IR) band and spatial resolution up to 10 cm. Satellite images have a lower spatial resolution (but lately there are images with an accuracy of better than 50 cm), but they provide more spectral bands (typically RGB + IR, but 16-band images, RGB + 2IR + SWIR bands are also available), taken in one scene. The individual bands of these multispectral images are selected with respect to atmospheric windows and are defined by the wavelengths of the respective intervals:

Another method of imaging is to scan a large number (typically 200 or more) of narrow spectral bands (bandwidth about 10 nm). These images provide near-continuous spectral information at each point (or small area given by the spatial resolution of the image) of the territory of interest. These so-called hyperspectral images can be obtained by aerial and satellite imaging.

Aerial images are used to create high-precision digital terrain models (*DMRs*). In recent years, satellite radar data (e.g. *InSAR*) with comparable accuracy, but with sensing of larger areas in one scene, have been used for creating *DMR* or tracking movements (especially vertical ones).

The advantages of aerial photography are:
- *high positional accuracy* (5 – 10 cm) of captured data (but after labour-demanding removal of geometric distortions);
- *less atmospheric distortion* (flying in clear weather and below cloud cover).

The advantages of satellite imagery are:
- *a more comprehensive* view of the situation in a given territory, i.e. it provides an image of a vast area on a single image under the same meteorological, light and temperature conditions;
- *regular and repeated* measurements of the same area (only 1 day for some types of images!, usually 15 – 20 days);
- *immediate* access to the scanned data (maximum few hours after scanning).

With an area of up to 1 km^2 of most of the monitored *EBs* (including the area of their impact), it is best to use images with sub-meter resolution with at least one *IR* band. Such a requirement is met by archive colour aerial images in combination with very high resolution satellite multispectral images (4- and 8-band images).

3.3 The results

Monitoring of EBs in selected Slovak localities by remote sensing methods consisted of analysis, interpretation and synthesis of data from images in order to:
- determine areal and spatial extent of EB;
- monitor the historical evolution of pollution by comparing images from different time periods;
- provision of spatial information for existing monitoring facilities or, where appropriate, documentation for the construction of new monitoring systems.

First of all, it was necessary to carry out a site search for the possibility of using remote sensing methods (remote sensing), i.e. finding all available information about the site, its historical development, ongoing activities, sources and types of pollution, carrying out field reconnaissance. Archives of existing remote sensing images were studied and suitable images were selected for use based on temporal and spatial parameters. In justified cases, new imaging parameters were entered and the required imaging dates were agreed.

A geoinformation system (GIS) project has been prepared in which all available spatial data on the existing site have been integrated: geological subsoil, digital terrain model, existing buildings, preliminary delimitation of EB and its anticipated polluted environment (e.g. in the range of micro-catchment below EB), planimetric data including watercourses, settlements and transport. Spatial distributions of parameters that exceeded the standard for relevant geological environmental factors, such as soil, surface and groundwater, were inserted into the project in the form of isolines.

Archive remote sensing images of multiple time periods can be delivered in various global coordinate systems (e.g. UTM, WGS-84, ETRS-89). First of all, it was necessary to geo-reference these images to the national (local) coordinate system (S-JTSK) and at least in the area of EB and its surroundings precisely orthorectified the images based on detailed DMR. For orthorectification of satellite imagery, orthorectified aerial imagery and control point technique were used.

The next steps of individual images processing consisted of examining individual images using visualization techniques such as adjusting contrast, brightness and exposure, uniform colouring (using a colour tone histogram), edge operations to enhance the interface, examine textures, and so on. The result was a preliminary delimitation of interfaces, inhomogeneities and changes. Some images needed to remove noise and cloud from the image.

For multispectral images, a single band *merge* technique was used, with spatial resolution determined based on a panchromatic band and spectral resolution determined from the respective colour bands. The result was an image with full spectral and higher spatial resolution. The processed images were an input parameter for further processing.

Further processing was demanding on computational operations:

- *Spectral image extensions* were used to effectively enhance and track contrasts in the image and serve as a basis for pooling analysis. Factor analysis using *principal component analysis (PCA)* was used. Estimation of soil biomass and moisture was followed by the *Tasseled Cap* method (brightness-green/*NDVI*-moisture in RGB bands). The state of vegetation, its individual species, as well as the qualitative status was monitored by examining the texture, structural and colour changes of the *NDVI* index. *Iron oxide* indices were calculated according to the original LANDSAT methodology, generalized to use new types of satellite images (QuickBird, WorldView-2 /Tab. 3.1/, GeoEye). The interfaces, lines, and contrast areas of each image were marked and saved as a basis for tracking changes over time.
- *Classification – uncontrolled classification* was used in the first step (the input was the image itself, or the derived PCA scene). The results were used directly in the interpretation and as input parameters for defining the spectral properties of individual object types for *controlled classification*.
- *Change detection* (in case of chronologically assigned frames) – *change detection* – is an automated comparison of two or more frames by changing values at a given location. These can be original images, index values, image classification results, or comparison of stored contrast interfaces. This method was used to interpret the evolution of the territory over time.

Tab. 3.1 Landsat and WorldView-2 satellite imageries bands, waveband usage can also be generalized to other image types

Wave length [nm]	**Spectral localisation**	**Landsat band**	**WorldView-2 band**	**Essential applicability**
400 – 450	coastal	-	1	Coastal application, water penetration, deep water masks, material differentiation, shadow-tree water differentiation.
450 – 520 Landsat 450 – 510 WV-2	blue	1	2	Penetrates through water, therefore it is suitable for coastal water mapping, soil-vegetation resolution, forest type mapping, cultural object identification; coastal application, water penetration, discrimination of soil/vegetation, forest types, reef cover features.
520 – 600 Landsat 510 – 580 WV-2	green	2	3	Measurement of maximum green reflectance of vegetation, estimation of vegetation state, identification of cultural objects; crop types, sea grass and reefs, bathymetry.
585 – 625	yellow	-	4	Leaf coloration, plant stress, CO$_2$ concentration, algal blooms, sea grass and reefs, separability of iron formations, “true colour”.
630 – 690	red	3	5	Description of sensitivity in the area of chlorophyll absorption in order to distinguish plant species, identification of cultural objects; chlorophyll absorption, vegetation analysis, plant species and stress.
705 – 745	red edge	-	6	Vegetation health, stress, type and age, sea grass and reefs, land/no land, impervious from vegetated, turbidity, camouflage.
760 – 900 Landsat 770 – 895 WV-2	NIR near IR-1)	4	7	Determination of vegetation types, state and volume of biomass, determination of water bodies, determination of soil moisture; biomass surveys, plant stress, delineation of water bodies, soil moisture discrimination.
860 – 900	near IR-2	-	8	Biomass surveys, plant stress, materials differentiation
1,550 – 1,750	SWIR	5	-	Identification of water volume in soil and vegetation. Differentiation of snow and clouds.
10,400 – 12,500	TIR	6	-	Indication of vegetation stress, soil moisture resolution, thermal mapping, suitable e.g. in regional mapping of geological structures.

The results of the interpretation were confronted with the results of laboratory work; the calculated areas were verified in the field. The resulting layers were synthesized with geology knowledge, geochemical anomalies, geophysical work results, erosion-accumulation model and stored in a prepared GIS project, ready for visualization and publication (e.g. via the web).

In the course of 2 years, 161 environmental burdens on the territory of the Slovak Republic were processed using this methodical procedure. The best results with regard to the use of remote sensing methods were achieved in mining operations examples (heaps, tailings ponds and their environs) and at sites such as industrial and solid municipal waste landfills, depots, oil and unspecified contamination and some industrial sites.

At all these sites, EB and its contamination cloud reflected on the state of vegetation, which resulted in significant contrasts in parameters using different spectral properties of substances in the R and IR bands. Remote sensing images from several periods, in particular sub-meter resolution images available since 2003, have been used at each site. The results have been integrated into the final interpretation layer.

Examples of monitored sites are shown in Figs. 3.1 – 4. These are sites of the industrial site type (US-Steel, Košice) and industrial waste landfill type (Fe-sludge, Šulekovo).

3.3.1 Locality US-Steel, Košice:

Historic image (1950): was not available.

Recent observations (2000 – 2014):

Industrial area: The whole area is dusty/polluted (dust, fly ash?, tar, petroleum products, oils?). Around a branched in-house railway line dust/pollution (tar, petroleum products, oils?) are observed. From the territory of interest there were available high-quality time-lapse aerial and satellite images from y. 2002 to y. 2014 with spatial resolution up to 25 cm, or 50 cm *pan-sharpened* and with up to 8-spectral bands (WorldView-2). The images show a continuous intensive metallurgical activity, which brings with it a corresponding dusting and contamination of the premises as well as its immediate surroundings. The area

Figs. 3.1a, b, c: Monitoring of contamination of the industrial site (US Steel, Košice) from 2002 to 2013, indicating the spread of dust pollution (red arrows), towards the recipient (light blue arrows) and prevailing winds (green arrows). The most polluted areas are marked by yellow areas.

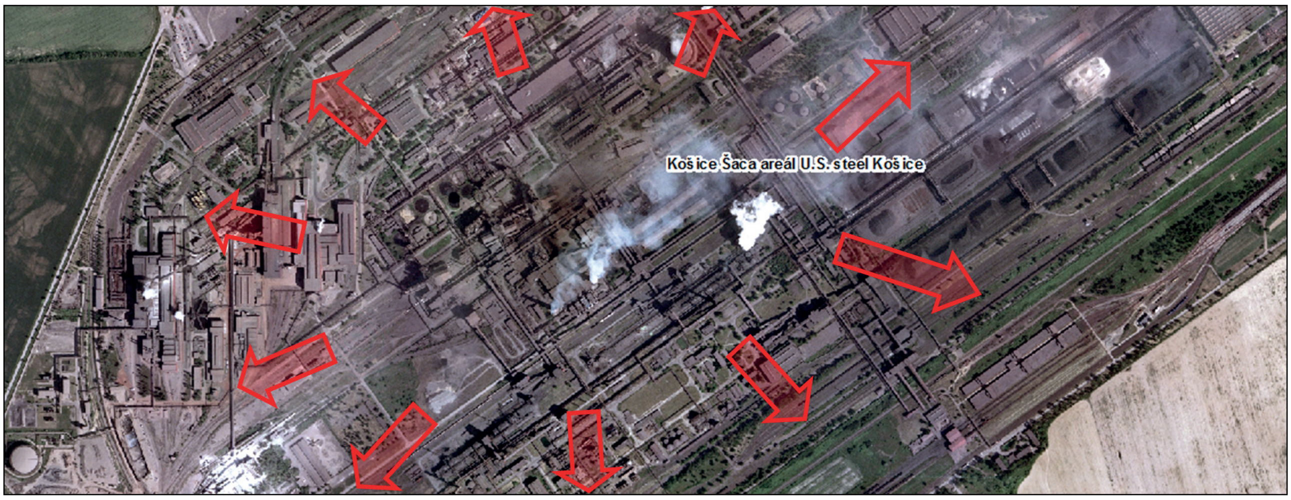

Fig. 3.1a Airborne image (2002)

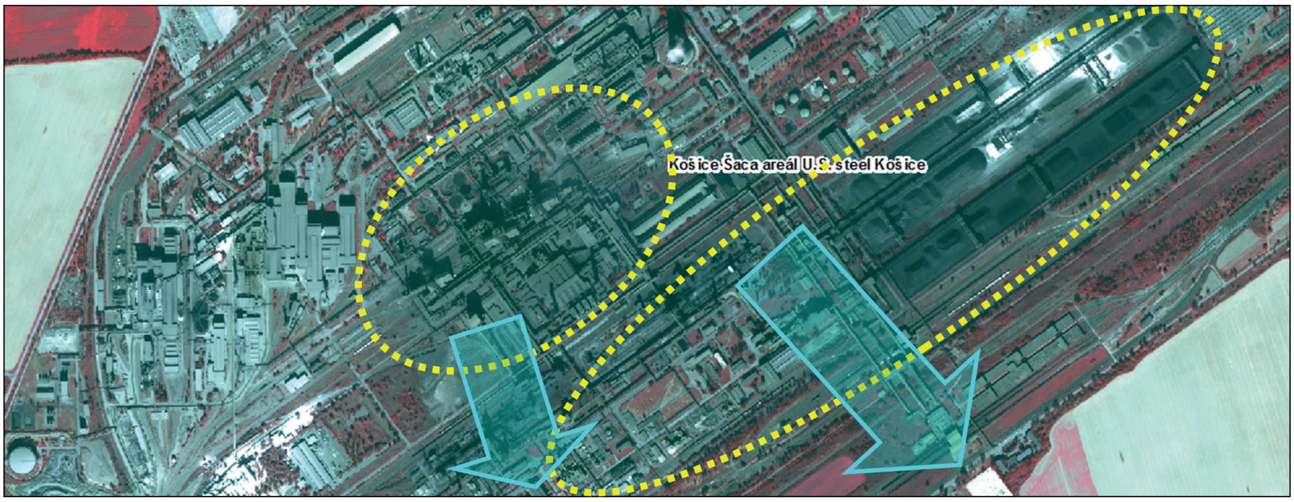

Fig. 3.1b Satellite image (2011), IR composition (WorldView-2: 7-5-3 bands)

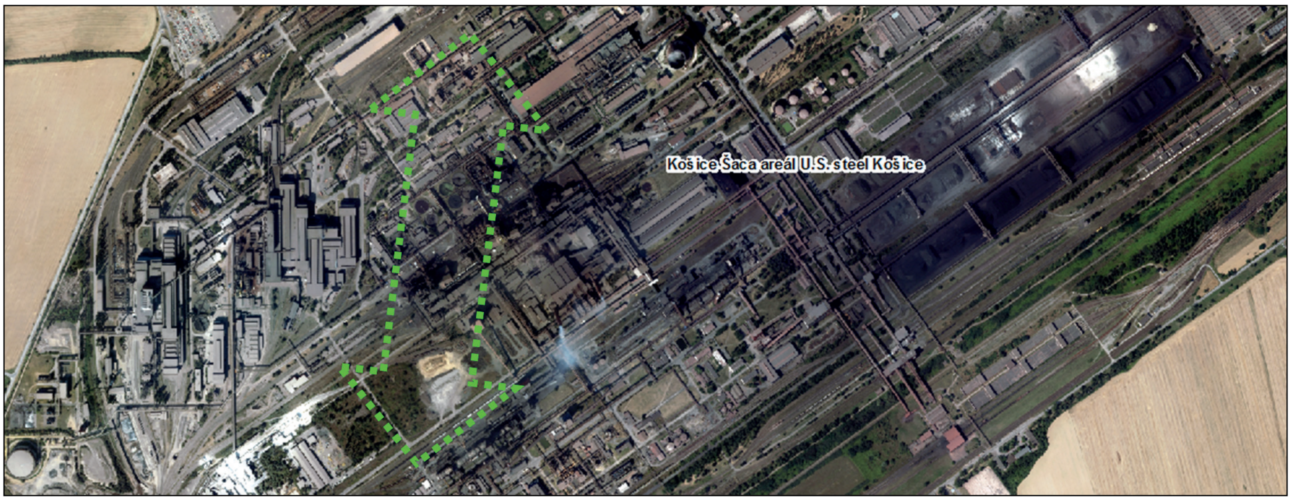

Fig. 3.1c Airborne image (2013)

Figs. 3.2a, b present selected compositional parameters of satellite imagery from 2011 highlighting the observed phenomenon – dusting of the area. The selected wavelength composition is projected into the R-G-B bands for visualization in the order shown in the description of the figs. 3.2a, b.

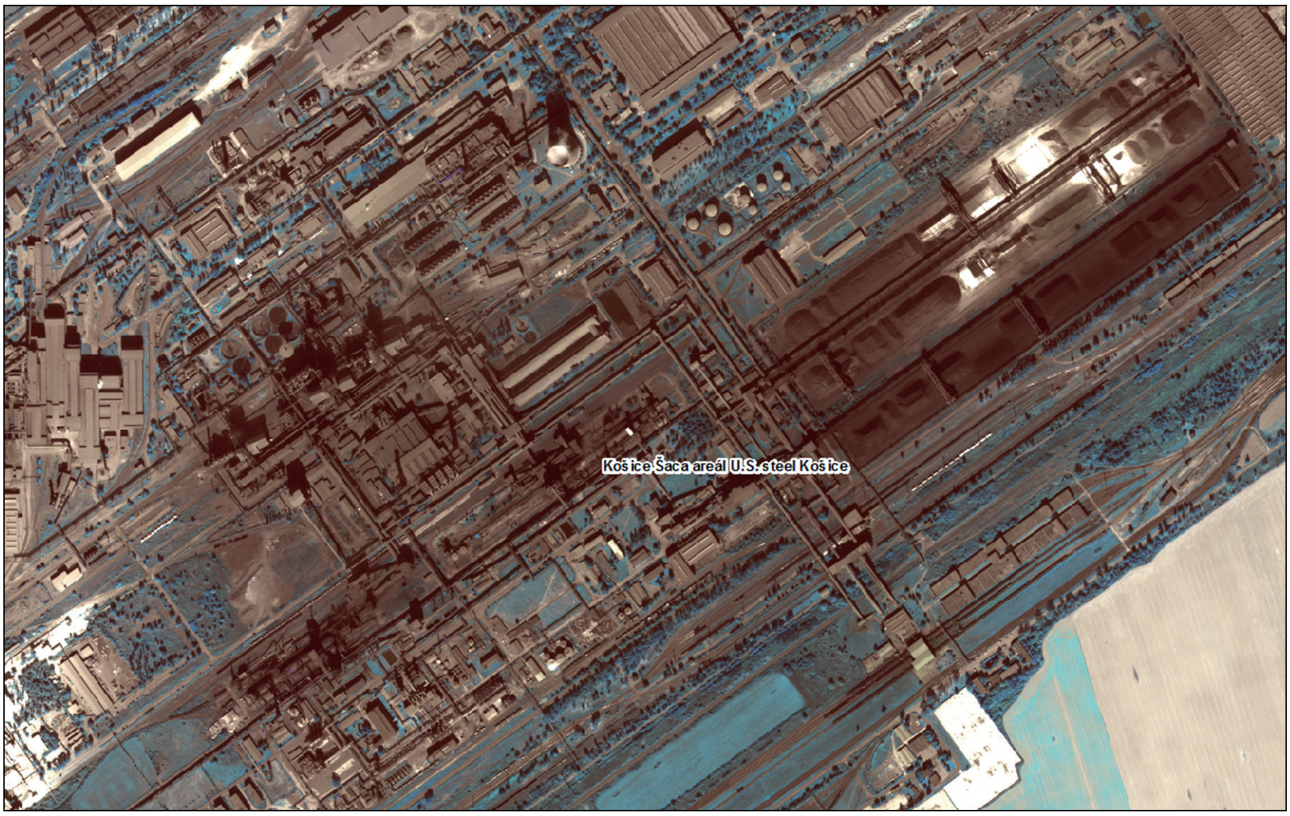

Fig. 3.2a Composition: "mining activity" (WorldView-2: 4-7-6 bands)

itself is the most polluted in its central part. In the *SW* part of the area is a large heap of ash, debris?. In the area there is a heap of slag, ash, as well as a tailing pond and a small lake. Around the heap, the vegetation is dusty, "overcast" with a coating. The surface area of the heap has increased accordingly in the period under review.

There is a pronounced north-south prevailing wind flow that affects the dustiness and pollution of buildings.

Vegetation: Time-lapse images showed changes in landscape and buildings: vegetation growth, vegetation excavation, construction of new buildings, demolition of buildings, partial reconstruction of buildings. The area was at least equally polluted during the whole monitored period, mainly in the *southern* part of the area. The nature of the vegetation in the immediate vicinity is damaged, probably due to contamination by metallurgical waste, oil substances, oils, fly ash? and other industrial substances, etc. Damage to vegetation, leaches on soils and other negative phenomena *are visible in the images*, both in the whole area and below the area in terms of surface

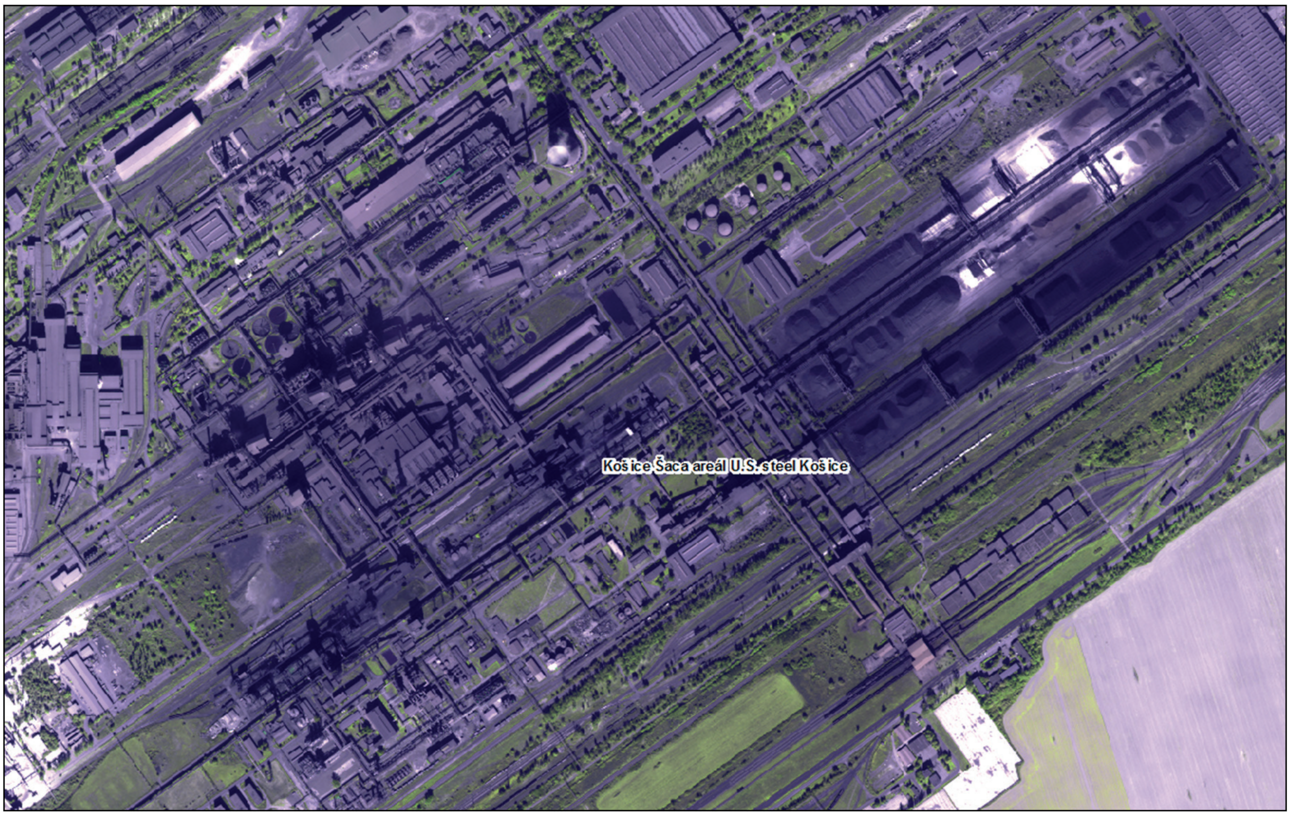

Fig. 3.2b Composition: "vegetation" (WorldView-2: 7-6-5 bands)

gradient (*S* edge), where the fields show clear subsurface and surface water flow; in these directions the pollution penetrates to the recipient.

General: The propagation directions appear in the images in the *J* direction. The images show alternation of drier and wetter locations (this is related to *subsoil layers* – soil type, lithology, as well as terrain *morphology*), which may indicate predominant directions of underground pollution spreading to the *south* of the *EB* site.

CONSEQUENCE: In view of *remote sensing* analysis, geophysical measurements results, available information on subsoil and terrain morphology, it was suggested from the perspective of remote sensing methods to monitor the situation in the southern part of the territory, continuing south towards the recipient.

3.3.2 Locality Fe-sludge, Šulekovo:

HISTORIC IMAGE (1950):

Landscape: The picture showed the course of the river Váh, its old oxbows and meanders, fragmented fields, before uniting the parcels during collectivization. The EB is situated in the old meanders of the Váh River.

RECENT OBSERVATIONS (2000 – 2014):

Vegetation: EB is also visible on Landsat image from y. 1999. As part of the project, the vegetation was observable on remote sensing images since 1999 to 2013.

Heap: Airborne image from y. 2002 – red Fe-sludge, in the southern part of the EB lake, on the edge is a lodge and around the dump is a concrete path. Satellite image from year 2008 – vegetation is "pushing" from the edges, it grows towards the centre of the area, the lake in the southern part is smaller (part of the area has dried up), the road in the surroundings is overgrown with weeds. Satellite image from year 2011 – vegetation is growing from the edges towards the centre of the area even more, on the contrary the lake area increased (compared to 2002), the road in the surroundings on the east and south sides is overgrown with weeds.

Part of the landfill in the S part is overgrown with grass. Airborne image from years. 2011 – 2013 – vegetation is growing more and more from the edges towards the centre of the area; the lake in 2011 has shrunk (but is larger than in 2002), the road in the vicinity of the E, S and W side overgrown with weeds. Part of the landfill in the southern part and over the edges is overgrown with grass. In the NE edge of the landfill we can see erosion bands/rills – the material flows through the edge to the road and fields. Airborne image from year 2013 with spatial resolution of 10 cm and IR band (!) – the vegetation is growing more and more from the edges towards the centre of the area, the lake has decreased compared to the previous image (but it is bigger than in 2002), the road in the vicinity of the E, S and W side overgrown with weeds. Landfills in the southern part and over the edges are overgrown with grass. The erosion processes occur all over the E edge of the landfill. Only the walls remained from the lodge at the E outskirts.

Surroundings: The images show the growth of vegetation appropriate to the observed time period. Interesting are indirect manifestations on vegetation (indications), which can be observed throughout the monitored period (2002

– 2013). Vegetation indicates leakages from landfill in groundwater flow directions, but in the NE area surface erosion effects are also visible towards the field, even with a direct manifestation (dried-up areas). There is also an interesting area of the former oxbow north of the EB and the state of vegetation in the SE direction from the EB to the river Váh.

Damage to vegetation, leaches on soils and other negative phenomena are visible in the pictures in the E, SE and S directions, but also on the NE edge at the EB.

General: The old oxbows, the streams visible in the historical image, are also observable on the present remote sensing images, either directly, or in the form of forests, vegetation, etc. The pollution propagation directions appear in the images in the E, S and SW directions. The images showed alternation of drier and wetter positions (this is related to underlying soil – soil type, lithology and terrain morphology), which indicate predominant directions of underground pollution spreading (these are mainly areas of old oxbows of the Váh River). The underlying interfaces (soil, lithology)/e.g. W of the landfill on airborne image from years 2012 – 2013, verified by geophysics results, sand/gravel positions were shown; by analogy, these observations can be generalized to a larger area.

CONSEQUENCE: With regard to the analysis of remote sensing images, geophysical measurements results, available information about the subsoil and terrain morphology, the monitoring from the perspective of remote sensing methods was proposed to the NE, E, S and SW parts of the territory, continuing on the NE and SE towards the recipient.

Figs. 3.3a, b represent historically oldest (1950) and the latest (2013) airborne image of the environmental burden Fe-sludge, Šulekovo.

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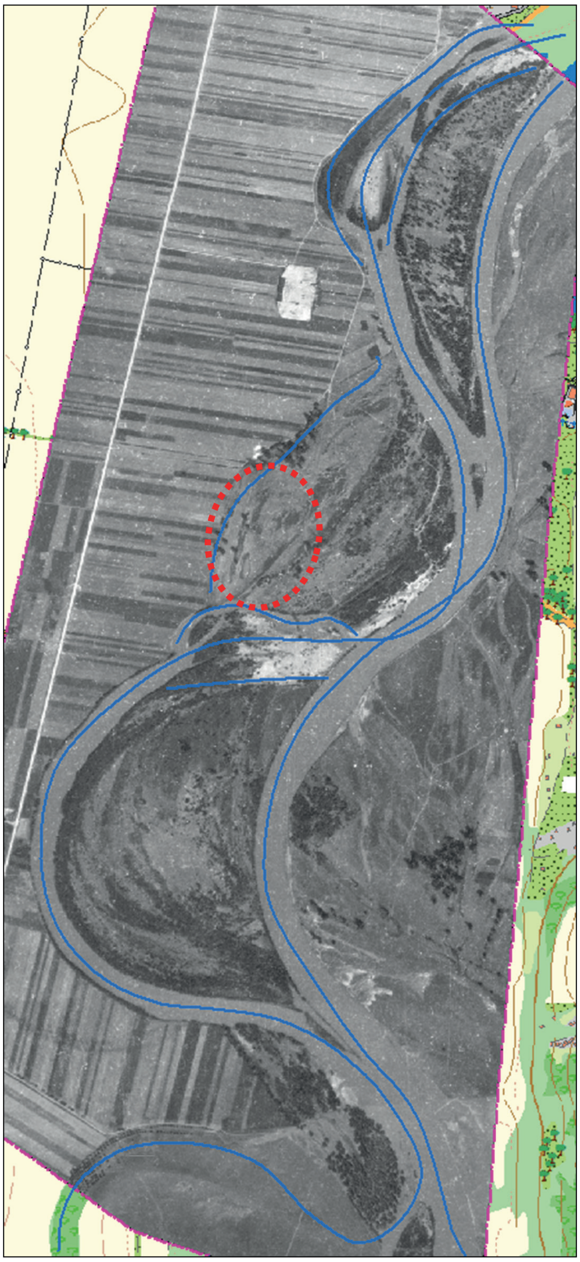

Fig. 3.3a Location of the future EB on a historical aerial photograph from 1950 (an old oxbow flows right through the site of the river Váh – marked with blue colour)

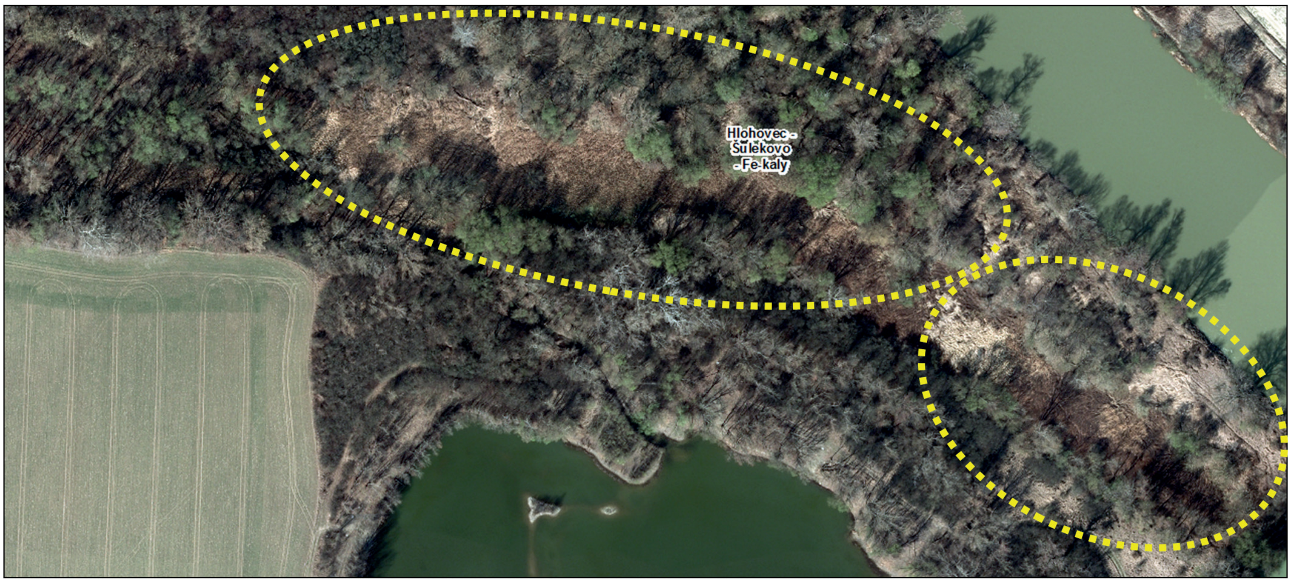

Fig. 3.3b Aerial image (2013), detail. Signs of pollution on vegetation in the vicinity of EB (brown, dried-up, burned vegetation)

Figs. 3.4 a, b, c depict monitoring of the development of the landfill of Fe-sludge (Šulekovo) from 2008 to 2013 with the marked landfill body (yellow broken line) and the direction of surface spread of contamination (yellow arrows).

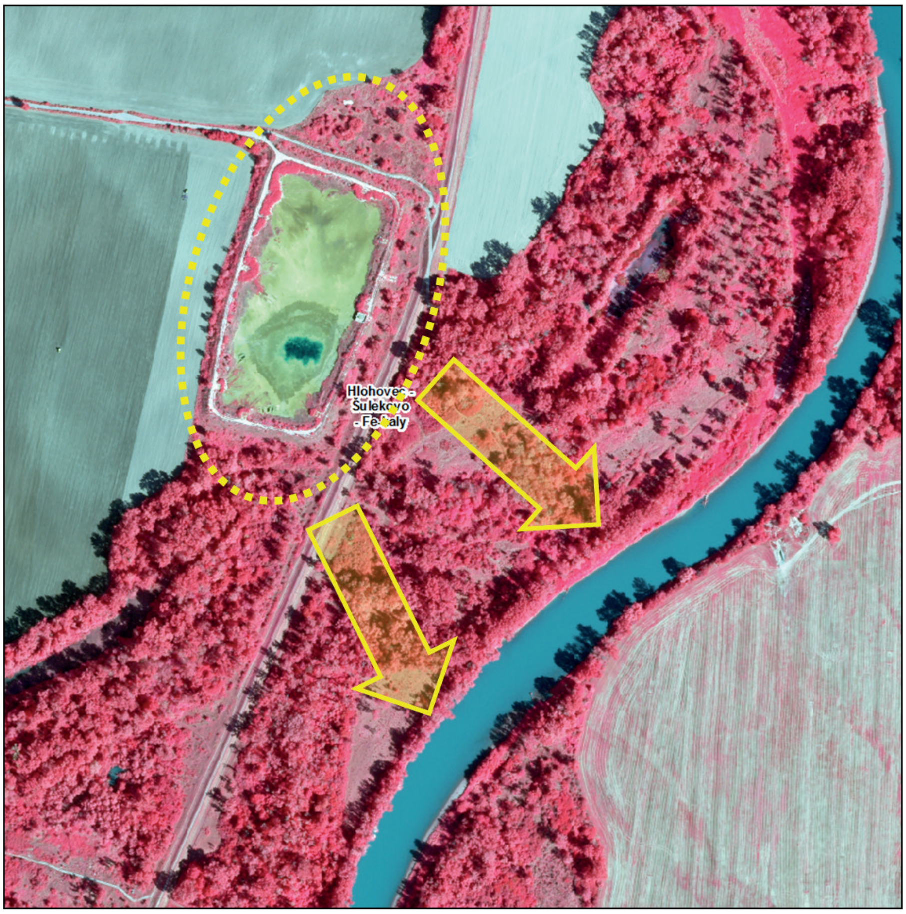

Fig. 3.4a Airborne image (2008) IR composition (4-3-2 bands)

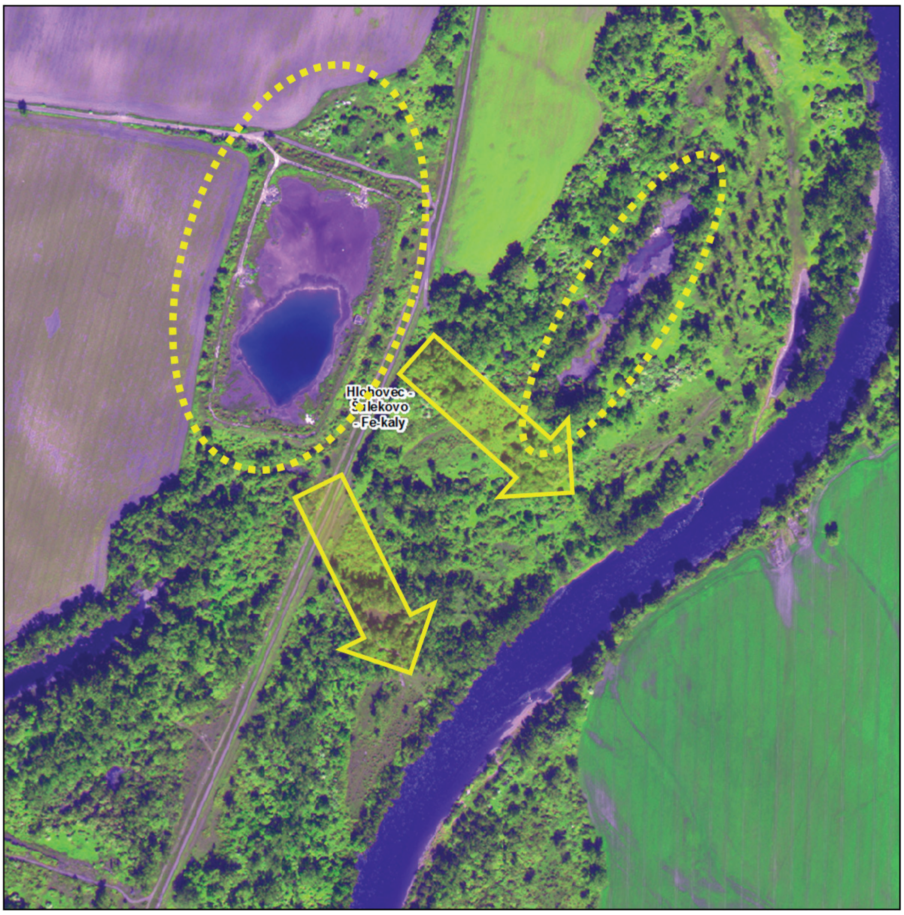

Fig. 3.4b Satellite image (2011) composition: "vegetation" (WorldView-2:7-6-5 bands)

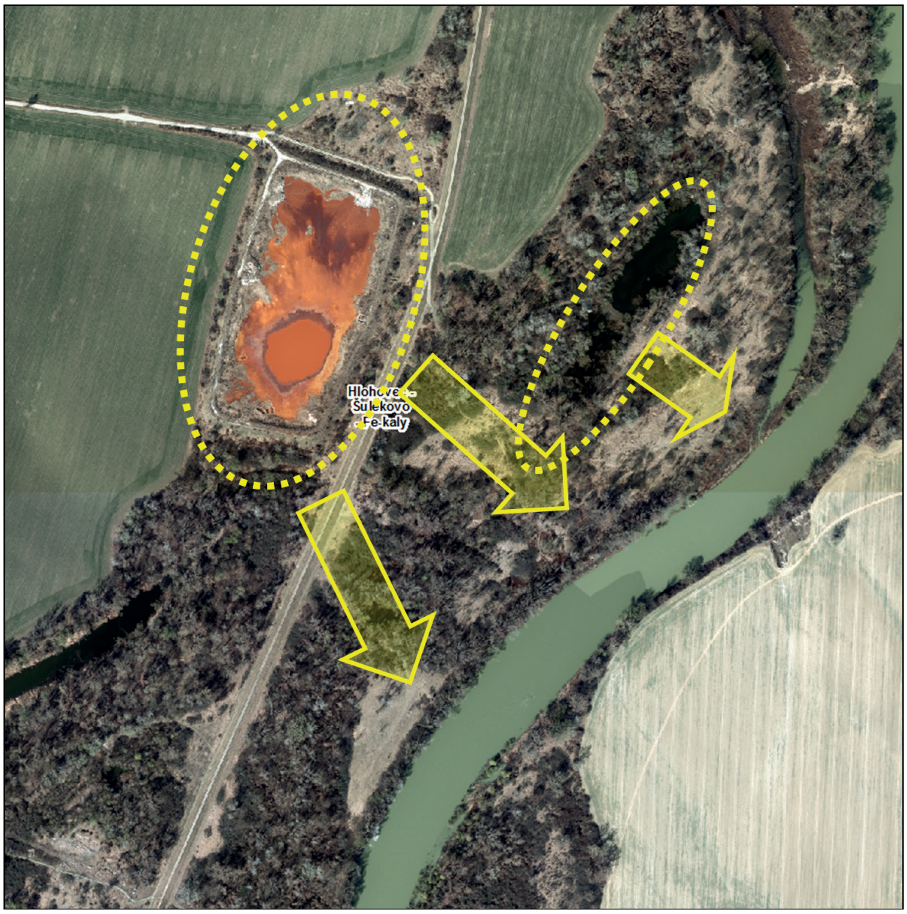

Fig. 3.4c Airborne image (2013), RGB

3.4 Conlusions

Environmental burdens are manifested differently in remote sensing images. The situation is well interpreted in locations which differ significantly from their surroundings in terms of spectral, texture or morphology, and/or their effects on their surroundings, especially vegetation and soil, are contrasting. The most typical examples are heaps, tailings ponds, but also various landfills for solid and municipal waste. In locations with a predominance of built-up areas (concrete, asphalt, buildings) the situation is more complicated and contrast effects are rare. In this type of sites it is not enough to use multispectral images, it is necessary to get a more accurate spectral view of the studied areas, e.g. by means of hyperspectral imaging, possibly using ground standards with simultaneous scanning of the area. With the buried EBs, it depends on the composition of the deposited material. For all types, field research is therefore necessary to verify the findings, or vice versa, to support the identified field and laboratory results by in-situ and historical exploration of the site and its surroundings.

During the work we verified a large number of remote sensing methodologies. For the EB sites the best and most effective procedures were summarized in the solution methodology:

1. 1) *Use a series of remote sensing images from multiple time periods* to interpret the images;
2. Perform an initial thorough analysis of the sites from all available text and map documents as well as archive images of remote sensing.
3. According to the results of this analysis, define the site at:
   a) sites with prevailing buildings, concrete, asphalt surfaces, etc. ("industrial" sites);
   b) sites with sufficient vegetation ("vegetation" sites);
   c) sites of small-scale area (area up to 10 km^2);
   d) large areas (over 10 km^2).
4. Map scale detail selection:
   a) The best scale of detail of map data for small-scale localities is 1: 2,000 (permissible from 1: 5,000 – 1: 1,000). Use of airborne and satellite imagery with sub-meter accuracy (WorldView2/3, Quick-Bird, GeoEye-1, Pléiades);
   b) The best scale of detail of map data for large-area sites is 1: 10,000 (permissible from 1: 25,000 – 1: 5,000). Use of satellite imagery with 5 – 10 m accuracy (e.g. RapidView).
5. Transformation of all data and images into the National Coordinate System (S-JTSK) and the most accurate orthorectification of images based on very accurate DMR;
6. Method of *pan-sharpening* to create images with as detailed spatial resolution as possible while

maintaining the spectral characteristics of individual bands;

7. Compute only the so-called “representative” parameters over *pansharp* image:
    - for “vegetation” sites:
        - 4band satellite and airborne imagery: TasseledCap (*brightness-greeness-wetness*, i.e. *PAN-NDVI-humidity*);
    - 8band satellite imagery: “vegetation” (*7-6-5*), (NIR_1-RedEdge-Red);
    - for “industrial” sites:
        - 4band: principal components -> conversion to 3 uncorrelated bands;
        - 8band *satellite imagery:* “mining activity” (*4-7-6*), (Yellow-NIR_1 – RedEdge);
    - for all sites:
        - uncontrolled classification (important for multi-band satellite imagery and hyperspectral images);
        - controlled classification with calibration with respect to ground standards (to interpret class associations using dendrograms);
8. Use of *change detection* method;
9. Save the results in the GIS.

The representative parameters listed are sufficient for most tasks of this type.

In the near future of *remote sensing* in environmental issues addressing, we can see the following:

- *multispectral satellite imagery* with a spatial resolution better than 50 cm (US Government Permission to release such data for civilian use as of 2014) and with as many spectral bands as possible. The images available: WorldView-2 and in particular WorldView-3 with 30 cm resolution for ***PAN***, 1.2 m for *VNIR* (8 bands), 3.7 m for *SWIR* (8 bands) and 30 m for *CAVIS* imaging (12 bands) / available from February 2015/.
- *hyperspectral* aerial images with 25 – 50 cm spatial resolution for VNIR (48 – 256 bands), 2 – 4 m for SWIR (selectable number of bands) and about 4 m for thermal imaging (selectable number of bands). Such data were used in the Slovak Republic in the geological task of the Survey of Selected Environmental Burdens in the Slovak Republic, which was completed in 2016. According to the latest information, two further phases of this project will be solved at present.

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4. Influence of Monitored Environmental Burdens on Groundwater and Surface Water Quality – General Results

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Abstract: Since 2012, the State Geological Institute of Dionýz Štúr has been carrying out tasks related to the monitoring of contaminated sites, so-called environmental burdens, currently at 309 sites. The aim of the work is to monitor the release of pollutants into the environment (especially groundwater and surface water) and to assess trends in the development of contamination. A large number of data on groundwater and surface water quality are collected and analysed as part of the monitoring work.

The chemical composition of water is often changed around environmental burdens and is shifting from standard types, such as Ca-HCO_3 and Ca-Mg-HCO_3, to types with a higher proportion of substances of secondary origin (Na^+, Cl^-, SO_4^{2-}), which is reflected in the frequent occurrence of anthropogenically modified water types such as Ca-Na-Cl-HCO_3, Ca-Mg-HCO_3-SO_4, etc. Pollution is also often manifested by an increase in the total dissolved solids and high conductivity values. Due to contamination from landfills as well as some other types of contamination, frequent occurrence of increased contents of boron, Cl^-, NH_4^+, SO_4^{2-} and increased conductivity values are observed. Concerning the organic compounds, chlorinated hydrocarbons, especially cis-1,2-dichloroethene, dichloromethane, tetrachloroethene, trichloroethene, chloroethene, appear to be the most problematic at the sites of concern. Regarding the mining sites monitoring, elevated concentrations of some trace inorganic elements, especially As, Cu, Zn, Cd, Sb, were found above the quality criteria. The results show that up to 56 sites (approx. 18%) of environmental burdens are characterized by a significant impact on the quality of groundwater or surface waters from the point of view of contents that do not meet IT criteria according to the MoE SR Directive No. 1/2015-7 for the preparation of risk analysis of contaminated area and do not meet criteria according the Government Regulations no. (EC) No 269/2010 laying down requirements for the achievement of good water status. Up to 78 sites of EB did not detect the spread of groundwater or surface water pollution – no indicator exceeded the IT criterion according to the MoE SR Directive No. 1/2015-7 or the limit value according to Government Regulation no. 269/2010.

Key words: monitoring, environmental burdens, chemical composition, quality, groundwater, surface water

4.1 Introduction

Since 2012, the State Geological Institute of Dionýz Štúr (SGIDŠ) has been carrying out tasks related to the monitoring of contaminated sites, so-called environmental burdens (EB), currently at 309 sites (Fig. 1.1, article 1 of this volume). The aim of the work is to monitor the release of pollutants into the environment (especially groundwater and surface water) and to assess trends in the development of contamination. The sites concerned are areas of various industrial enterprises, railway areas, abandoned and buried waste dumps, unsecured pesticide and other hazardous substance storages, military areas, sites affected by mineral extraction and their processing and others.

In recent years, the systematic attention has been paid to the issue of EB both in Slovakia and abroad. Quite complexly, the issue of exploration, monitoring and remediation of EB is described in the work Šottník et al. (2015). Between 2012 and 2015, a number of detailed geological investigations of selected EB were carried out which also included an assessment of the risk analysis of the polluted area, such as works of Urban et al. (2015): Vrakunská cesta – CHZJD landfill; Tupý et al. (2015a): Martin – SNP army barracks; Pramuk et al. (2015a): Žilina – eastern industrial zone; Pospiechová et al. (2015): Krompachy – Kovohuty. In the mining areas survey was carried out, for example, in locations Poproč – Petrova dolina Valley (Auxt et al., 2015a), Smolník – mining of pyrite ores (Auxt et al., 2015b), Rudňany – ore mining and treatment (Pramuk & Matiová, 2015), Pezinok – the area of ore mines and old mining works (Tupý et al., 2015b), Slovinky – ore mining and treatment (Pramuk et al., 2015b).

One of the pilot works in monitoring of the EB was the geological task titled “Monitoring of impact of EB on geological factors of the environment in selected Western Carpathians regions” (Vybíral et al., 2005). The aim of this task was to use new methodologies and techniques of exploration and monitoring, to assess impacts of anthropogenic sediments to environment, to determine qualitative and quantitative parameters of pollution, extent and degree of pollution of the rock environment and to establish temporal and spatial trends in pollution spread. Among other works related to monitoring of the EB impact can be mentioned, for example, at the site Bekaert Hlohovec, joint stock company (Pospiechová et al., 2014), pollution monitoring in ENO Nováky (Ingár & Auxt, 2017) and monitoring in TESLA Stropkov, joint stock company (Bachňák, 2019). The system for the detection and monitoring of environmental damage arising from mining activities was developed by Vrana et al. (2005). Abroad, the issue of the EB monitoring s described, for example, in works by Akankpo & Igboekwe (2011), Golder Associates (2010), Narany et al. (2014), Texas Groundwater Protection Committee (2013), Brown et al. (2014), DSITI (2017), McLean et al. (2019).

Monitoring of environmental burdens in Slovakia follows the results of several geological tasks of the

Ministry of Environment of the Slovak Republic. In 2006 – 2008 the geological task of Systematic Identification of Environmental Burdens of the Slovak Republic (Paluchová et al., 2008; www.enviroportal.sk) was carried out. The results of the above project were followed in 2009 by the project "Regional Studies of Impact of Environmental Burdens to Environment" (Helma, 2010), the aim of which was a detailed assessment of the impact of environmental burdens to environment in individual self-governing regions of the Slovak Republic. Since 2016, monitoring of EB in Slovakia is carried out mainly in connection with the projects financed from the Operational Programme Environment:

- Monitoring of Environmental Burdens at Selected Sites in Slovakia (Kordík & Slaninka et al., 2015).
- Investigation of Environmental Burdens at Selected Sites in the Slovak Republic – 54 sites (2012 – 2015).
- Probable environmental burdens – investigation at selected sites in the Slovak Republic – 87 sites (2014 – 2015).
- Projects of Remediation of Environmental Burdens at Selected 19 sites (2013 – 2015).

By carrying out these geological tasks, detailed data on pollution, spatial development and pollution changes, natural attenuation of contamination and detailed interpretation of the data were obtained.

In the article, attention is paid to selected results of monitoring of environmental burdens focused on groundwater and surface water. The basic statistical processing of selected physico-chemical indicators determined in waters and the comparison of analytical results with legislation (in particular with the Directive of the Ministry of Environment of the Slovak Republic No. 1/2015-7 on elaboration of the risk analysis of contaminated area, or Government Regulation No. 269/2010 laying down requirements for achieving good water status) are stated.

4.2 Methods

Monitoring of groundwaters and surface waters in areas of environmental burdens is a systematic observation of time changes of concentrations of selected pollutants indicative for a given site. Monitoring of EB is carried out in accordance with EU legislation, in particular Directive 2000/60/EC of the European Parliament and of the Council of 28 October 2000 establishing a framework for Community action in the field of water policy and Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration.

Implementation of the monitoring itself is preceded by the establishment of a **monitoring programme**, in which field measurements, sampling and laboratory work carried out in a defined monitoring network were carried out. The monitoring programme is reviewed and updated annually based on new results and information. **Water sampling** is performed on the basis of the procedures specified in the relevant Slovak Technical Standards (STN) of the STN EN ISO 5667 series. The following physico-chemical properties are usually determined directly in the field: water temperature, air temperature, pH, specific electrolytic conductivity (at 25 °C), dissolved oxygen content, percentage oxygen saturation, groundwater level (if relevant), or other indicators. An overview of realized field measurements in groundwaters and surface waters for the period 2012 – 2018 is given in Tab. 4.1.

Laboratory analyses of water samples are implemented according to a proposed monitoring programme and are carried out in the Geoanalytical Laboratories of

Tab. 4.1 Number of realized field measurements in groundwaters and surface waters for the period 2012 – 2018

	Boreholes drilled in 2014 – 2015	Reconstructed boreholes	Old boreholes	Other groundwater sources – house-hold wells, springs	Surface water	Total
Groundwater level	12,357	1,692	2,178	217	-	16,454
pH	10,806	1,296	1,580	471	1,719	15,872
Specific electrolytic conductivity	13,060	1,695	2,323	633	2,340	20,051
Dissolved oxygen	11,598	1,421	1,798	523	2,033	17,373
Oxygen saturation	10,409	1,313	1,459	464	1,775	15,420
Water temperature	13,129	1,652	2,287	629	2,330	20,027
Air temperature	11,515	1,533	1,859	566	2,158	17,631
Eh	6,670	439	998	273	996	9376
Sensorial properties (descriptive)	11,157	1,406	1,705	514	1,924	16,706

SGIDŠ (GALs), Regional Centre Spišská Nová Ves. The GALs performs a complete service of analytical, physico-chemical and mineralogical works for the needs of geological research and investigation, exploration of mineral resources, regional geology, hydrogeology, geochemical mapping and environmental monitoring. The GALs are an accredited testing laboratory in accordance with ISO/IEC 17025: 2005 and were established in 1997 as the Reference Laboratory of the Ministry of the Environment of the Slovak Republic for geology and analysis of geological materials and the rock environment. The quality assurance and quality control system in the laboratory are designed to ensure that the tests performed give correct results with declared accuracy. The control system includes, in particular, internal and external control analyses, the use of certified reference materials, repetition of tests by different analytical methods, operator verification, regular participation in interlaboratory comparisons and proficiency testing programs, testing long-term stability of measuring systems.

Overview of the number of the most frequently determined chemical indicators in waters in 2012 – 2018 is presented together with the basic statistical parameters of selected physico-chemical indicators analysed in waters in Tab. 4.2.

The results of analytical analyses of groundwaters and surface waters (selected physico-chemical indicators) are **statistically processed and compared with legislation** (for groundwater with indicating and intervention criteria given in the Directive of the Ministry of Environment of the Slovak Republic No. 1/2015-7 on elaboration of the risk analysis of contaminated area and for surface water with the limit values given in the Government Regulation No. 269/2010 laying down requirements for achieving good water status).

Methodological procedures used in the groundwater and surface water monitoring in the areas of EB are in more details listed in the article 1 of this issue of the journal and in Kordík & Slaninka et al. (2015).

4.3 Results

In most cases, groundwater or surface waters are the most important transport medium when monitoring EB. For this reason, in the EB monitoring, sampling and analytical work concentrate on the aquatic environment. Tab. 4.2 shows the basic statistical parameters of selected physico-chemical parameters determined in waters, Tab. 4.3 shows a number of exceedances of IT and ID values of selected indicators in groundwater according to the Directive of the Ministry of Environment of the Slovak Republic No. 1/2015-7 and Tab. 4.4 shows a number of exceedances of limit values of selected indicators in surface waters pursuant to the Government Regulation No. 269/2010 laying down requirements for the achievement of good water status.

In general, in the chemical composition of groundwater and surface water, the presence of calcium predominates in the case of macro-element cations, with an average content of 120 $mg.l^{-1}$, followed by sodium (average 58.5 $mg.l^{-1}$), magnesium (average 35.6 $mg.l^{-1}$) and potassium (mean 16.3 $mg.l^{-1}$) – Tab. 4.2. The anions are dominated by bicarbonates (average 400 $mg.l^{-1}$), followed by sulphates (average 135 $mg.l^{-1}$), chlorides (average 110 $mg.l^{-1}$) and nitrates (average 24.9 $mg.l^{-1}$). The basic chemical composition of water is often changed in the areas of environmental burdens and is shifted from standard types (e.g. Ca-Mg-HCO_3 type) to those with a higher proportion of substances of secondary origin (Na^+, Cl^-, SO_4^{2-}). As shown in Tab. 4.2, there is a clear variability of the values of all mentioned indicators reflecting very different conditions of formation of chemical composition of groundwaters and surface waters.

Pollution often occurs in areas of EB by increasing the values of total dissolved solids. The average **conductivity** in water reflecting the solute content was calculated at 118 $mS.m^{-1}$, which means an increased value compared to waters with a dominant natural formation of chemical composition (Tab. 4.2). The occurrence of extreme conductivity values above 300 $mS.m^{-1}$ (884 measurements) or above 1,000 $mS.m^{-1}$ (117 measurements) is quite frequent (the maximum measured value reached 28,600 $mS.m^{-1}$; Ružomberok – SCP site). Sites with the highest conductivity values in water (above 1,000 $mS.m^{-1}$) are Ružomberok – SCP (producer of paper and pulp, loc. no. 303), Hlohovec – Šulekovo – Fe-sludge (loc. no. 165; maximum 3,230 $mS.m^{-1}$), Komárno – Harčáš (loc no. 212; maximum 2,719 $mS.m^{-1}$), Nižný Hrabovec – Bukocel (loc. no. 28; maximum 2,870 $mS.m^{-1}$), Lednické Rovne – landfill Podstránie (loc. no. 66; maximum 2,130 $mS.m^{-1}$), Trnovec nad Váhom – RSTO dump (loc. no. 49; maximum 1,539 $mS.m^{-1}$), Čičava – area of agricultural cooperative (loc. no. 324; maximum 1,340 $mS.m^{-1}$), Bojná – landfill – part A (loc. no. 85; maximum 1,227 $mS.m^{-1}$).

The **pH value** of the polluted areas may vary. On average, groundwater pH was found close to neutral (7.25), but in extreme cases it reached very low values below 5 (21 measurements) or very high values above 9.5 (122 measurements). Strongly basic environment was found especially at the sites Istebné – OFZ – slug piles (loc. no. 50; maximum 13.25), Prešov – Duklianske barracks (loc. no. 235; maximum 13.6), Žiar nad Hronom – ZSNP, a.s. – sludge field (loc. no. 142; maximum 12.267), Medzibrodie nad Oravou – landfill Široká (loc. no. 51; maximum 10.69). On the other hand, strongly acidic pH values were measured mainly at the Predajná – landfill sites (locs. no. 58, 59; minimum 1.4), Smolník – pyrite ore extraction (loc. no. 207; minimum 2.79), Polomka – wood-logging plant (loc. no. 101; minimum 3.67). However, extreme pH values are usually limited spatially, as processes in the rock environment have the potential to adjust the pH in the waters towards neutral values.

From Tab. 4.3 it is evident that the most exceedances of IT value was found in the case of **TOC** (2,004 determinations at 103 sites), which is also influenced by the strict (low) IT limit for TOC (5 $mg.l^{-1}$). Pollution with organic substances (which is indicated by TOC) is relatively frequent in Slovakia, especially at sites such as municipal landfills and oil pollution areas or other contamination sources. The highest content of TOC (1,460 $mg.l^{-1}$) was found at the site Komárno – area after the Soviet Army (loc. no. 253). Extremely high levels of TOC (above 50 mg.l^{-1}) were also determined at the Predajná – industrial landfill Predajná I. (loc. no. 59; maximum 253.8 mg.l^{-1}), Krompachy – Kovohuty (former smelting plant, loc. no. 314; maximum 395 mg.l^{-1}), Lednické Rovne – Podstránie dump (loc. no. 66; maximum 1,300 mg.l^{-1}), Bojná – landfill – part A (loc. no. 85; maximum 296 mg.l^{-1}), Komárno – Madzagoš (loc. no. 109; maximum 104 mg.l^{-1}), Hnúšťa – former SLZ factory (loc. no. 116; maximum 83.5 mg.l^{-1}), Bratislava – Vrakuňa – CHZJD landfill (loc. no. 203; maximum 218,8 mg.l^{-1}).

Similarly to TOC, concentrations of the next group organic pollution indicator (**COD$_{Mn}$**) were observed in values above IT at 53 sites (Tab. 4.3). Extremely high levels of COD$_{Mn}$ (above 50 mg.l^{-1}) were found at the sites Lednické Rovne – Podstránie dump (loc. no. 66; maximum 408 mg.l^{-1}), Bojná – landfill – part A (loc. no. 85; maximum 150.1 mg.l^{-1}), Plešivec – retention reservoirs (loc. no. 104; maximum 118 mg.l^{-1}), Hnúšťa – former SLZ factory (loc. no. 116; maximum 104.5 mg.l^{-1}), Žiar nad Hronom – ZSNP sludge field (loc. no. 142; maximum 95 mg.l^{-1}), Hrabovčík – landfill (loc. no. 160; maximum 81 mg.l^{-1}), Hlohovec – Šulekovo – Fe-sludge (loc. no. 165; maximum 95.8 mg.l^{-1}), Jestice – pesticide storage (loc. no. 305; maximum 88.5 mg.l^{-1}), Jarabina – storage of agrochemicals (loc. no. 314; maximum 99.2 mg.l^{-1}), Komárany – storage of agrochemicals (loc. no. 326; maximum 1,176 mg.l^{-1}).

Pollution from landfills as well as some other types of contamination is associated with the occurrence of high levels (above IT) of **boron** (11 sites), **Cl^{-}** (40 sites), **NH$_4^+$** (87 sites) and **conductivity** (52 sites) – Tab. 4.3.

Extremely high contents of B (above 5 mg.l^{-1}) were observed especially at the sites Medzibrodie nad Oravou – landfill Široká (loc. no. 51; maximum 68 mg.l^{-1}), Snina – dump (loc. no. 64; maximum 123.8 mg.l^{-1}), Bojná – landfill – part A (loc. no. 85; maximum 7.84 mg.l^{-1}), Trnovec nad Váhom – pond America I (loc. no. 137; maximum 6.39 mg.l^{-1}), Žakovce – dump Úsvit (loc. no. 155; maximum 10.35 mg.l^{-1}), Hlohovec – Šulekovo – Fe-sludge (loc. no. 165; maximum 9.67 mg.l^{-1}). Extremely high levels of Cl^{-} (above 2,000 mg.l^{-1}) were observed mainly at sites Nováky – Chemical plants (loc. no. 1; maximum 4,140 mg.l^{-1}), Trnovec nad Váhom – RSTO dump (loc. no. 49; maximum 4,557 mg.l^{-1}), Hlohovec – Šulekovo – Fe-sludge (loc. no. 165; maximum 13,000 mg.l^{-1}), Prešov – Solivary (loc. no. 298; maximum 7,750 mg.l^{-1}). Extremely high levels of NH$_4^+$ (above 100 mg.l^{-1}) were monitored at sites Trnovec nad Váhom – RSTO dump (loc. no. 49; maximum 185 mg.l^{-1}), Lednické Rovne – Podstránie dump (loc. no. 66; maximum 852 mg.l^{-1}), Bojná – landfill – part A (loc. no. 85; maximum 779 mg.l^{-1}), Komárno – Madzagoš (loc. no. 109; maximum 259 mg.l^{-1}), Šaľa – Duslo – production of LAD and ammonium nitrate (loc. no. 149; maximum 164 mg.l^{-1}), Komárno – Harčáš (loc. no. 212; maximum 271 mg.l^{-1}), Bošany – tannery dump I (loc. no. 229; maximum 1,158 mg.l^{-1}), Žilina – Eastern Industrial Zone (loc. no. 251; maximum 353 mg.l^{-1}), Šurice – pesticide storage (loc. no. 281; maximum 558 mg.l^{-1}), Jarabina – agrochemical storage (loc. no. 312; maximum 247 mg.l^{-1}), Sačurov – old steam mill (loc. no. 327; maximum 879 mg.l^{-1}).

Among the organic substances, chlorinated hydrocarbons appear to be the most problematic within monitored EB, especially **cis- 1,2-dichloroethene** (29 sites above the IT value), **dichloromethane** (12 sites above the IT value), **tetrachloroethene** (39 sites above the IT value), **trichloroethene** (21 sites above the IT value) and **chloroethene** (26 sites above IT value) – Tab. 4.3.

Very high contents of cis- 1,2-dichloroethene (above 1 mg.l^{-1}) were found at the sites Zlaté Moravce – Calex (loc. no. 35; maximum 34.19 mg.l^{-1}), Banská Bystrica – Uľanka – chemical plant (loc. no. 38; maximum 64.911 mg.l^{-1}), Detva – PPS Group (loc. no. 40; maximum 6.144 mg.l^{-1}), Lučenec – laundries and dry cleaners (loc. no. 71; maximum 2.53 mg.l^{-1}), Žilina – east industrial zone (loc. no. 251; maximum 27.33 mg.l^{-1}), Pukanec – sludge dump Hampoch (loc. no. 254; maximum 2.488 mg.l^{-1}), Prešov – former ZPA plant (loc. no. 296; maximum 2.357 mg.l^{-1}).

Very high contents of dichloromethane (above 0.02 mg.l^{-1}) were observed at the sites Nováky – Chemical plants (loc. no. 1; maximum 0.048 mg.l^{-1}), Bratislava – CHZJD chemical plants (loc. no. 6; maximum 0.6 mg.l^{-1}), Piešťany – Chirana (loc. no. 22; maximum 0.0565 mg.l^{-1}), Banská Bystrica – Uľanka – Chemika (loc. no. 38; maximum 0.6 mg.l^{-1}), Lučenec – laundries and dry cleaners (loc. no. 71; maximum 0.06 mg.l^{-1}), Bratislava – Vrakuňa – landfill CHZJD (loc. no. 203; maximum 0.6 mg.l^{-1}), Levice – laundries and dry cleaners (loc. no. 217; maximum 0.0259 mg.l^{-1}), Považská Bystrica – area of former Považské Engineering Works (loc. no. 227; maximum 0.064 mg.l^{-1}), Žilina – east industrial zone (loc. no. 251; maximum 0.0363 mg.l^{-1}).

Very high levels of tetrachloroethene (above 1 mg.l^{-1}) were found at the sites Zlaté Moravce – Calex (loc. no. 35; maximum 6.482 mg.l^{-1}), Detva – PPS Group (engineering industry, loc. no. 40; maximum 6.312 mg.l^{-1}), Lučenec – laundries and dry cleaners (loc. no. 71; maximum 35.105 mg.l^{-1}), Banská Bystrica – former LOBB galvanizing plant (loc. no. 96; maximum 3.364 mg.l^{-1}), Rožňava – chlorinated hydrocarbon cloud at barracks (loc. no. 103; maximum 1.706 mg.l^{-1}), Pukanec – sludge dump Hampoch (loc. no. 254; maximum 23.159 mg.l^{-1}).

Very high contents of trichloroethene (above 1 mg.l^{-1}) were observed at the sites Zlaté Moravce – Calex (loc. no. 35; maximum 85.2 mg.l^{-1}), Banská Bystrica – Uľanka – chemical plant (loc. no. 38; maximum 64.4 mg.l^{-1}), Detva – PPS Group (loc. no. 40; maximum 14.475 mg.l^{-1}), Lučenec – laundries and dry cleaners (loc. no. 71; maximum 7.056 mg.l^{-1}), Žilina – eastern industrial zone (loc. no. 251; maximum 8.215 mg.l^{-1}), Pukanec – sludge dump Hampoch (loc. no. 254; maximum 1.74 mg.l^{-1}), Šurany – former ELITEX and STS area (loc. no. 293; maximum 2.32 mg.l^{-1}), Nováky – Military Repair Company (loc. no. 294; maximum 40.67 mg.l^{-1}).

Very high contents of chloroethene (above 0.1 mg.l^{-1}) were found at the sites Nováky – Chemical plants (loc. no. 1; maximum 6.973 mg.l^{-1}), Piešťany – Chirana (producer of medical devices, loc. no. 22; maximum 0.76 mg.l^{-1}), Piešťany – Tesla (loc. no. 26), Kežmarok – OKTAN (loc. no. 31; maximum 0.477 mg.l^{-1}), Zlaté Moravce – Calex (engineering, production of refrigerators, loc. no. 35; maximum 5.186 mg.l^{-1}), Banská Bystrica – Uľanka – Chemika (loc. no. 38; maximum 9.84 mg.l^{-1}), Detva – PPS Group (loc. no. 40; maximum 0.38 mg.l^{-1}), Rimavská Sobota – area after Soviet Army (loc. no. 240; maximum 0.206 mg.l^{-1}), Žilina – east industrial zone (loc. no. 251; maximum 37.983 mg.l^{-1}), Pukanec – sludge dump Hampoch (loc. no. 254; maximum 0.42 mg.l^{-1}).

Substances from the PAH group (**polycyclic aromatic hydrocarbons**) were monitored over ID or IT criteria mainly at the sites Zvolen – Bučina – Black Impregnation (timber industry, loc. no. 36), Zvolen – Bučina – Old Depot (loc. no. 81) and Medzev – Strojsmalt (loc. no. 81).

Strong oil pollution caused by high **hydrocarbon index** (C_{10}-C_{40}) above the IT criterion (0.5 mg.l^{-1}) was found at 35 sites (Tab. 4.3). Extremely high levels of C_{10}-C_{40} (above 10 mg.l^{-1}) were observed especially at the sites Bratislava – Chemika (loc. no. 4; maximum 4,715 mg.l^{-1}), Bratislava – Gumon (loc. no. 5; maximum 1,410 mg.l^{-1}), Kežmarok – OKTAN (loc. no. 31; maximum 126 mg.l^{-1}), Kysucké Nové Mesto – NN Slovakia (loc. no. 33; maximum 206 mg.l^{-1}), Zvolen – Bučina – black impregnation (loc. no. 36; maximum 227 mg.l^{-1}), Ružomberok – brick factory (loc. no. 113; maximum 30.8 mg.l^{-1}), Medzev – Strojsmalt (loc. no. 156; maximum 302 mg.l^{-1}), Kysucké Nové Mesto – municipal landfill (loc. no. 210; maximum 21.6 mg.l^{-1}), Kuchyňa – airport (loc. no. 219; maximum 5,110 mg.l^{-1}), Čierna nad Tisou – transshipment station (loc. no. 248; maximum 689 mg.l^{-1}), Komárno – area after Soviet Army (loc. no. 253; maximum 1,730 mg.l^{-1}), Trstená – former fuel store Hámričky (loc. no. 319; maximum 18.4 mg.l^{-1}), Žilina – ZVL area (loc. no. 331; maximum 23.3 mg.l^{-1}).

Slovakia is also characterized by exceeding the quality criteria for some trace inorganic elements. **Arsenic and antimony**, especially due to the inclusion of mining sites in monitoring, exceed IT criteria in groundwater at 26 sites (As) and 13 sites (Sb), respectively (Tab. 4.3).

Very high concentrations of As (above 0.5 mg.l^{-1}) are mainly associated with industrial activity, these are the sites Istebné – OFZ – slug piles (loc. no. 50; maximum 2.054 mg.l^{-1}), Medzibrodie nad Oravou – landfill Široká (loc. no. 51; maximum 7.8 mg.l^{-1}), Svit – landfill Chemosvit (loc. no. 56; maximum 1.25 mg.l^{-1}), Bojná – landfill – part A (loc. no. 85; maximum 2.3 mg.l^{-1}), Bystričany – ENO – temporary tailings (loc. no. 139; maximum 3.047 mg.l^{-1}), Žiar nad Hronom – ZSNP sludge field (loc. no. 142; maximum 1.494 mg.l^{-1}), Bratislava – Vrakuňa – CHZJD landfill (loc. No. 203; maximum 1.31 mg.l^{-1}), Žilina – east industrial zone (loc. no. 251; maximum 1.96 mg.l^{-1}), Krompachy – Kovohuty (loc. no. 314; maximum 2.01 mg.l^{-1}). From mining sites, the highest concentrations of As were found at the sites Poproč – Petrova dolina Valley (loc. no. 213; maximum 7.25 mg.l^{-1}) and Pezinok – ore and old mining area (loc. no. 231; maximum 0.645 mg.l^{-1}).

Very high concentrations of Sb (above 0.3 mg.l^{-1}) were observed at the sites Lazisko – Liptovská Dúbrava (loc. no. 13; maximum 0.49 mg.l^{-1}), Dúbrava – galleries and heaps at Liptovská Dúbrava (loc. no. 14; maximum 11.3 mg.l^{-1}), Banská Bystrica – Uľanka – Chemika (loc. no. 38; maximum 0,326 mg.l^{-1}), Partizánska Ľupča – galleries and heaps at Magurka (loc. no. 78; maximum 0.642 mg.l^{-1}), Poproč – Petrova dolina Valley (loc. no. 213; maximum 7.176 mg.l^{-1}), Pezinok – ore and old mining area (loc. no. 231; maximum 0.518 mg.l^{-1}), Krompachy – Kovohuty (loc. no. 314; maximum 2.2 mg.l^{-1}).

Exceedance the IT criterion for **aluminum** was found in groundwater at 16 sites (Tab. 4.3). The IT criterion for Al^{3+} (0.4 mg.l^{-1}) seems to be too strict, as in Slovakia the natural concentration of Al^{3+} up to 0.5 mg.l^{-1} is quite common. Very high levels of aluminum in groundwater (above 2 mg.l^{-1}) were measured at the sites Krásny Brod – Monastýr dump (loc. no. 132; maximum 7.64 mg.l^{-1}), Smolník – pyrite ores (loc. no. 207; maximum 110 mg.l^{-1}), Poproč – Petrova dolina Valley (loc. no. 213; maximum 30.48 mg.l^{-1}), Dežerice – VAB sludge basin (loc. no. 261; maximum 8.33 mg.l^{-1}).

Less problematic indicators in our monitored sites include some trace elements (Co, Cr, Cu, Hg, Mo, Pb, V), fluorides, nitrites, cyanides, phenols, chlorobenzenes, substances of BTEX and PCB.

From the point of view of physico-chemical indicators measured in situ in **surface waters**, a rather frequent phenomenon is the deteriorated quality of surface water caused by the deterioration of oxygen regime (38 sites) and occurrence of high values of conductivity (46 sites) and pH (45 sites) – Tab. 4.4. Pollution from landfills as well as some other types of contamination (e.g. agriculture) is associated with increased levels of Cl^- (16 sites), NH_4^+ (35 sites), SO_4^{2-} (19 sites), Na^+ (22 sites), Ca^{2+} (37 sites), Mn^{2+} (32 sites), NO_3^- (24 sites) and conductivity (46 sites). Among the trace elements in surface waters, above-limit contents of As (29 sites), Cr (15 sites), Al^{3+} (26 sites), Cu (19 sites) and Zn (14 sites) were observed.

Specific organic substances were found **in surface water** at above-limit concentrations as follows:

cis- 1,2-dichloroethene (18 sites) – the most: Lučenec – laundries and dry cleaners (loc. no. 71; maximum 0.26 mg.l^{-1}), Zubrohlava – sludge field – heavy engineering factories Námestovo (loc. no. 15; maximum 0.0766 mg.l^{-1}), Zlaté Moravce – Calex (loc. no. 35; maximum 0.281 mg.l^{-1}), Banská Bystrica – Uľanka – chemical plant (loc. no. 38; maximum 0.0365 mg.l^{-1}), chlorobenzene: Bratislava – CHZJD chemical plants (loc. no. 6; maximum 0.053 mg.l^{-1}),

- dichlorobenzene: Predajná – industrial dump Predajná I. (loc. no. 59; maximum 0.0088 mg.l^{-1}),
- benzene, toluene and xylenes: Pozdišovce – former state material reserves (loc. no. 221; maximum 0.198 mg.l^{-1} for benzene; maximum 0.549 mg.l^{-1} for toluene; maximum 0.556 mg.l^{-1} for xylenes),
- substances from the PAH group (acenaphthene, anthracene, dibenzo(a,h)anthracene, benzo(a)pyrene, benzo(b)flouranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, phenanthrene, fluoranthene, fluorene, chrysene, indeno(1,2,3-c,d)pyrene, naphthalene, pyrene): Zvolen – Bučina – black impregnation (loc. no. 36), Predajná – industrial

dump Predajná II. (loc. no. 58), Zvolen – Bučina – old depot (loc. no. 81), Polomka – woodworking plant (loc. no. 101),

- dichloromethane: Piešťany – Chirana (loc. no. 22; maximum 0.0825 mg.l^{-1}), Rimavská Sobota – Gemer nákup (loc. no. 112; maximum 0.0233 mg.l^{-1}),
- tetrachloroethene: Zlaté Moravce – Calex (loc. no. 35; maximum 0.818 mg.l^{-1}), Bratislava – Petržalka – Matador (loc. no. 48; maximum 0.0177 mg.l^{-1}), Lučenec – laundry and dry cleaning (loc. no. 71; maximum 0.407 mg.l^{-1}),
- trichloroethene: Stropkov – TESLA (loc. no. 20; maximum 0.0139 mg.l^{-1}), Zlaté Moravce – Calex (loc. no. 35; maximum 8.517 mg.l^{-1}), Banská Bystrica – Uľanka – Chemika (loc. no. 38; maximum 0.0106 mg.l^{-1}), Predajná – industrial dump Predajná II. (loc. no. 58; maximum 0.059 mg.l^{-1}), Lučenec – laundries and dry cleaners (loc. no. 71; maximum 0.066 mg.l^{-1}), Rožňava – cloud of chlorinated hydrocarbons at the barracks (loc. no. 103; maximum 0.0132 mg.l^{-1}), Strážske – Chemko – waste channel (loc. no. 222; maximum 0.0243 mg.l^{-1}),
- polychlorinated biphenyls (PCB): Strážske – Chemko – waste channel (loc. no. 222).

Tab. 4.2 Basic statistical parameters of selected physico-chemical parameters determined in waters

	unit	**mean**	**median**	**standard deviation**	**minimum**	**maximum**	**number of measurements / analyses**
pH	-	7.25	7.16	0.61	1.171	13.76	15,858
water temperature	^{o}C	11.99	12	3	0	32.5	20,021
specific electrolytic conductivity	mS.m^{-1}	118	84	305	0.609	28,600	19,987
dissolved O_2	mg.l^{-1}	3.71	2.76	3.63	0	22.70	17,335
Eh	mV	132	137	164	-978	2,016	9,370
NH_4^+	mg.l^{-1}	3.94	0.1	31.20	<0.005	1,158	9,987
NO_2^-	mg.l^{-1}	0.28	0.02	4.52	<0.005	164	2,777
NO_3^-	mg.l^{-1}	24.9	4.98	127	0.046	8,012	9,412
PO_4^{3-}	mg.l^{-1}	0.22	0.03	1.34	<0.01	50	3,284
F^-	mg.l^{-1}	1.62	0.1	29.5	<0.01	975	1,378
Cl^-	mg.l^{-1}	110	28.8	463	0.43	13,000	9,661
SO_4^{2-}	mg.l^{-1}	135	59.2	431	<0.5	23,064	9,647
HCO_3^-	mg.l^{-1}	400	371	292	0	5,673	8,155
TOC	mg.l^{-1}	7.24	2.31	33.1	0.1	1,460	8,902
COD_{Mn}	mg.l^{-1}	5.51	1.6	29.70	0.03	1,466	6,647
Na^+	mg.l^{-1}	58.5	21.0	189.00	0.09	5,300	8,209
K^+	mg.l^{-1}	16.3	3.29	95.50	0.1	2,980	8,169
Ca^{2+}	mg.l^{-1}	120	102	169	2.4	5,470	8,161
Mg^{2+}	mg.l^{-1}	35.6	24.5	45.70	0.04	2,100	8,153
Fe_{total}	mg.l^{-1}	2.74	0.046	24.10	<0.001	1,040	8,504
Mn	mg.l^{-1}	1.37	0.10	25.0	<0.001	1,560	8,586
SiO_2	mg.l^{-1}	20.0	13.0	80.0	0.04	2,052	3,769
Li^+	mg.l^{-1}	0.04	0.01	0.63	<0.001	38	3,691
Ba	mg.l^{-1}	0.17	0.079	3.74	<0.005	317	7,776
Sr	mg.l^{-1}	0.49	0.375	0.63	0.015	14.30	7,709
B	mg.l^{-1}	0.37	0.064	6.88	0.006	620	8,354
Al	mg.l^{-1}	0.14	0.02	2.36	<0.005	110	7,824
As	µg.l^{-1}	27.1	1.2	245	<0.1	7,800	8,520
Sb	µg.l^{-1}	16.7	1	244	<0.1	11,300	8,039
Se	µg.l^{-1}	1.83	1	6.86	<1	140	868
Be	µg.l^{-1}	0.14	0.1	1.99	<0.1	121	3,680
Cr	µg.l^{-1}	47.1	2	963	<0.1	35,000	8,412
Cd	µg.l^{-1}	5.59	0.3	157	<0.1	6,680	8,067
Cu	µg.l^{-1}	40.1	2	455	<0.01	15,200	8,324
Ni	µg.l^{-1}	61.1	2	1,3970	<0.1	80,523	8,292

Tab. 4.2 – continue

	unit	mean	median	standard deviation	minimum	maximum	number of measurements / analyses
Pb	µg.l^{-1}	5.85	5	91.0	<0.1	7,810	8,503
Mo	µg.l^{-1}	9.64	4	48.9	<0.1	956.8	7,515
Ag	µg.l^{-1}	1.06	1	0.70	<1	15	3,714
Co	µg.l^{-1}	4.07	2	25.7	<1.5	1,089	7,413
Sn	µg.l^{-1}	30.4	30	10.0	<0.5	300	3,667
V	µg.l^{-1}	4.58	3	29.8	<1	1,590	7,482
Zn	µg.l^{-1}	5213	5	165,207	<0.01	7,090,000	8,443
COD$_{Cr}$	mg.l^{-1}	41.3	11	172	<0.5	4,188	1,651
P-total	mg.l^{-1}	0.21	0.02	2.37	<0.01	118	3,990
surfactants	mg.l^{-1}	3.04	0.07	72.8	<0.01	2,200.00	915
Hg	µg.l^{-1}	7.99	0.1	529	<0.01	36,000	4,636
CN$^{-}_{total}$	mg.l^{-1}	0.04	0.005	1.12	<0.002	44.6	1,597
phenol index	mg.l^{-1}	0.05	0.01	0.43	<0.01	11.4	1,698
adsorbable organic halogens	mg.l^{-1}	0.13	0.03	0.45	<0.004	6.59	624
extractable organic halogens	mg.l^{-1}	1.59	0.005	30.5	<0.001	775	1,029
hydrocarbon index (C$_{10-40}$)	mg.l^{-1}	6.72	0.02	149	<0.005	6,350	7,087
1,1,1 – trichloroethane	µg.l^{-1}	0.33	0.2	3.03	<0.1	137	4,375
1,1 – dichloroethene	µg.l^{-1}	0.94	0.2	11.7	<0.1	754	5,559
1,2 cis – dichloroethene	µg.l^{-1}	154	0.2	5,293	<0.1	374,065	5,490
1,2 trans – dichloroethene	µg.l^{-1}	1.73	0.2	44.1	<0.1	3,071	5,492
1,2 – dichloroethane	µg.l^{-1}	1.62	0.2	47.1	<0.1	2,530	3,023
dichloromethane	µg.l^{-1}	3.30	0.2	33.6	<0.1	600	2,912
tetrachloroethene	µg.l^{-1}	161	0.2	1307	<0.1	35,105	5,520
carbon tetrachloride	µg.l^{-1}	3.22	0.2	60.6	<0.1	2,068	3,087
trichloroethene	µg.l^{-1}	171	0.2	2,497	<0.03	85,200	5,546
chloroethene	µg.l^{-1}	21.4	0.2	582	<0.1	37,983	5,050
chloroform	µg.l^{-1}	1.33	0.2	12.1	<0.1	456	3,237
1,2 – dichlorobenzene	µg.l^{-1}	0.37	0.2	2.22	<0.1	65.3	2,949
1,3 – dichlorobenzene	µg.l^{-1}	0.31	0.2	1.34	<0.1	52.6	2,946
1,4 – dichlorobenzene	µg.l^{-1}	0.50	0.2	3.4	<0.1	104	2,947
benzene	µg.l^{-1}	17.4	0.2	235	<0.1	9,367	4,041
ethylbenzene	µg.l^{-1}	15.6	0.2	271	<0.1	9,780	4,042
chlorobenzene	µg.l^{-1}	72.1	0.2	929.97	<0.1	28,700	2,939
toluene	µg.l^{-1}	23.4	0.2	647.58	<0.01	28,550	4,041
styrene	µg.l^{-1}	0.70	0.2	17.14	<0.1	975	3,307
xylene	µg.l^{-1}	14.4	0.2	182.98	<0.1	7,186	3,949
acenaphthene	µg.l^{-1}	6.70	0.03	149.20	<0.002	5,679	3,336
anthracene	µg.l^{-1}	0.73	0.003	21.96	<0.001	887	3,910
dibenzo(a,h)anthracene	µg.l^{-1}	0.05	0.03	1.07	<0.002	60.6	3,341
benzo(a)pyrene	µg.l^{-1}	0.52	0.005	20.33	<0.001	1,122	3,946
benzo(b)flourantene	µg.l^{-1}	1.61	0.03	69.29	v0.001	3,794	3,935
benzo(g,h,i)perylene	µg.l^{-1}	0.12	0.03	2.94	<0.001	137	3,938
benzo(k)fluoranthene	µg.l^{-1}	0.20	0.03	6.90	<0.001	373	3,938
phenanthrene	µg.l^{-1}	6.48	0.02	181.04	<0.001	7,681	3,946
fluoranthene	µg.l^{-1}	4.24	0.003	133.88	<0.001	5,072	3,947
fluorene	µg.l^{-1}	6.71	0.015	181.74	<0.001	7,000	3,360
chrysene	µg.l^{-1}	0.92	0.003	30.04	<0.001	1,326	3,946

Tab. 4.2 – continue

	unit	mean	median	standard deviation	minimum	maximum	number of measurements / analyses
indeno(1,2,3-c,d)pyrene	μg.l^{-1}	0.16	0.03	5.08	<0.001	284	3,940
naphthalene	μg.l^{-1}	6.73	0.04	150.20	<0.001	8,451	4,000
pyrene	μg.l^{-1}	4.09	0.006	127.97	<0.001	5,527	3,923
PCB28	μg.l^{-1}	0.04	0.003	0.38	<0.001	4	1,007
PCB52	μg.l^{-1}	0.04	0.003	0.37	<0.001	4	1,027
PCB101	μg.l^{-1}	0.04	0.003	0.37	<0.001	4	1,028
PCB118	μg.l^{-1}	0.04	0.003	0.37	<0.001	4	1,028
PCB138	μg.l^{-1}	0.04	0.003	0.37	<0.001	4	1,028
PCB153	μg.l^{-1}	0.04	0.003	0.37	<0.001	4	1,028
PCB180	μg.l^{-1}	0.04	0.003	0.37	<0.001	4	1,028
acenaphthylene	μg.l^{-1}	0.19	0.03	4.08	<0.002	178	3,191
benzo(a)anthracene	μg.l^{-1}	3.45	0.003	118.06	<0.001	5,061	3,329

Tab. 4.3 Number of exceedances of IT and ID values of selected indicators in groundwater according to the Directive of MoE SR No. 1/2015-7

Parameter	ID value (mg.l^{-1})	IT value (mg.l^{-1})	Number of exceedances of ID value	Number of analyses with exceedance of IT value	Number of sites with exceedances of IT value
Al^{3+}	0.25	0.4	93	154	16
As	0.05	0.1	105	224	26
Cd	0.005	0.02	75	57	7
Ni	0.1	0.2	33	105	6
Sb	0.025	0.05	75	185	13
Zn	1.5	5	46	36	5
B	0.5	5	729	44	11
Cl^-	150	250	413	653	40
NH_4^+	1.2	2.4	412	1,091	87
COD_{Mn}	5	10	617	482	53
TOC	2	5	2,083	2,004	103
hydrocarbon index (C_{10}-C_{40})	0.25	0.5	165	346	35
specific electrolytic conductivity (mS.m^{-1})	200	300	885	884	52
pH	6.0 – 6.5 and 8.5 – 9.0	less than 6.0 and more than 9.0	784	302	29
phenol index	0.015	0.06	69	52	8
benzene	0.015	0.03	30	101	15
polycyclic aromatic hydrocarbons – sum	0.06	0.12	21	54	7
chlorobenzene	0.015	0.03	20	74	5
dichlorobenzene	0.0015	0.003	21	47	6
1,2- dichloroethene cis	0.025	0.05	89	452	29
dichloromethane	0.015	0.03	25	23	12
tetrachloroethene	0.01	0.02	174	603	39
trichloroethene	0.025	0.05	103	360	21
chloroethene (vinyl chloride)	0.005	0.01	90	227	26

Tab. 4.4 Number of exceedances of limit values of selected indicators in surface waters according to the Government Regulation of the SR no. 269/2010

Parameter	**Unit**	**Limit value ($mg.l^{-1}$)**	**Number of analyses with exceedance of limit value**	**Number of sites with exceedances of limit value**
dissolved O_2	$mg.l^{-1}$	more than 5	192	38
pH	-	6 – 8.5	209	45
specific electrolytic conductivity	$mS.m^{-1}$	110	379	46
COD_{Cr}	$mg.l^{-1}$	35	87	9
TOC	$mg.l^{-1}$	11	167	24
Mn	$mg.l^{-1}$	0.3	152	32
Ca^{2+}	$mg.l^{-1}$	100	220	37
Cl^-	$mg.l^{-1}$	200	79	16
SO_4^{2-}	$mg.l^{-1}$	250	83	19
Na^+	$mg.l^{-1}$	100	107	22
F^-	$mg.l^{-1}$	1.5	31	10
$N\text{-}NH_4^+$	$mg.l^{-1}$	1	188	35
$N\text{-}NO_2^-$	$mg.l^{-1}$	0.02	87	24
$N\text{-}NO_3^-$	$mg.l^{-1}$	5.0	126	23
Al^{3+}	$mg.l^{-1}$	0.2	59	26
As	$mg.l^{-1}$	7.5*	152	29
Cr_{total}	$mg.l^{-1}$	9*	29	15
Cu	$mg.l^{-1}$	8.8*	58	19
Zn	$mg.l^{-1}$	52*	66	14
1,2- dichloroethene cis	$mg.l^{-1}$	0.4	40	18
tetrachloroethene	$mg.l^{-1}$	10**	11	3
trichloroethene	$mg.l^{-1}$	10**	14	7

Notes:

* *To the values stated in the Government Regulation of the SR no. 269/2010, it is necessary to add the background concentration values for a given surface water body of Slovakia as specified in a separate document (Bodiš et al., 2010)*

** *average value*

List of EB sites with a significant impact on the quality of groundwater or surface waters from the point of view of contents that do not meet IT criteria according to the Directive of the Ministry of Environment of the Slovak Republic No. 1/2015-7, resp. the Government Regulations of the Slovak Republic no. 269/2010, is shown in Tab. 4.5. These are 56 sites representing a wide range of economic activities that have been carried out in the past. In particular, various industrial activities, waste facilities and some mining sites are represented. Several of the sites listed in Tab. 4.5 are subject to a more detailed assessment in the article 1 of the next issue of this journal.

Spread of contamination in groundwaters or surface waters was not found at the 81 EB sites (Tab. 4.6). However, this does not mean that there is no risk of contamination of the natural environment, especially where the source of pollution has not been removed.

Tab 4.5 Overview of the occurrence of pollutants at the most contaminated monitored localities of environmental burdens from the point of view of contents not meeting the IT criteria according to the Directive of the MoE of the SR No. 1/2015-7

ID	**Environmental burden**	**Indicators exceeding the IT values**
1	Nováky – Chemical plants	As, Cl^-, NH_4^+, COD_{Mn}, TOC, C_{10}-C_{40}, conductivity, pH, benzene, chlorobenzene, dichlorobenzene, 1,2-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethene cis, dichloromethane, tetrachloroethene, carbon tetrachloride, trichloroethene, vinyl chloride
4	Bratislava – Chemika	NH_4^+, COD_{Mn}, TOC, conductivity, anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, phenanthrene, chrysene, indeno(1,2,3-c,d)pyrene, dichloromethane, tetrachloroethene
5	Bratislava – Gumon	NH_4^+, COD_{Mn}, TOC, C_{10}-C_{40}, anthracene, chrysene, carbon tetrachloride
6	Bratislava – Chemical plants of Juraj Dimitrov	Cl^-, NH_4^+, COD_{Mn}, TOC, pH, benzene, ethylbenzene, chlorobenzene, dichlorobenzene, trichlorobenzene, dichloromethane, tetrachloroethene, carbon tetrachloride, trichloroethene, vinyl chloride
8	Bardejov – Heavy engineering factory	1,2-dichloroethene cis, dichloromethane, tetrachloroethene, trichloroethene

Tab 4.5 – continue

ID	Environmental burden	Indicators exceeding the IT values
20	Stropkov – TESLA	NH_4^+,1,2-dichloroethene cis, trichloroethene
21	Nové Mesto nad Váhom – landfill Mnešice – Tušková	Cl^-, NH_4^+, TOC, conductivity, 1,2-dichloroethene cis, tetrachloroethene
22	Piešťany – Chirana	NH_4^+,1,2-dichloroethene cis, dichloromethane, trichloroethene, vinyl chloride
24	Sereď – Nickel plant – landfill dump	Cd, Ni
25	Sereď – Nickel plant – former factory area	Cd, Co, Ni, Zn, NH_4^+, conductivity
26	Piešťany – Tesla – contamination plume under the housing estate	1,2-dichloroethene cis, vinyl chloride
27	Nové Zámky – Real H.M. – terminal	NH_4^+, COD_{Mn}, TOC, C_{10}-C_{40}, benzene
30	Sliač – airport – south	As, COD_{Mn}, TOC, C_{10}-C_{40}, naphthalene, dichlorobenzene, tetrachloroethene
33	Kysucké Nové Mesto – NN Slovakia	Cl^-, C_{10}-C_{40}, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene
35	Zlaté Moravce – Calex	NH_4^+, COD_{Mn}, 1,2-dichloroethene cis, 1,2-dichloroethene trans, tetrachloroethene, trichloroethene, vinyl chloride
36	Zvolen – Bučina – black impregnation	COD_{Mn}, TOC, C_{10}-C_{40}, FNI, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, fluoranthene, phenanthrene, chrysene, indeno(1,2,3-c,d)pyrene, naphthalene, pyrene
38	Banská Bystrica – Chemika	As, Sb, NH_4^+, COD_{Mn}, TOC, 1,2-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethene cis, 1,2-dichloroethene trans, dichloromethane, tetrachloroethene, trichloroethene, vinyl chloride
40	Detva – PPS Group	COD_{Mn}, TOC, C_{10}-C_{40}, 1,1-dichloroethene, 1,2-dichloroethene cis, 1,2-dichloroethene trans, tetrachloroethene, trichloroethene, vinyl chloride
41	Pohorelá – Strojsmalt Holding	COD_{Mn}, tetrachloroethene
43	Zvolen – Bučina – white impregnation	NH_4^+, COD_{Mn}, TOC, C_{10}-C_{40}, pH, FNI, naphthalene, tetrachloroethene
50	Istebné – OFZ – heap of debris	As, Cr, Mo, NH_4^+, TOC, conductivity, pH
51	Medzibrodie nad Oravou – landfill Široká	As, B, Cl^-, F^-, NH_4^+, TOC, conductivity, pH
58	Predajná – industrial landfill Predajná II.	Al^{3+}, Sb, TOC, conductivity
59	Predajná – industrial landfill Predajná I.	Sb, NO_2^-, COD_{Mn}, TOC
65	Nové Zámky – locomotive depo – diagnostic centre	conductivity, 1,2-dichloroethene cis, tetrachloroethene, vinyl chloride
71	Lučenec – Laundry and dry cleaning	NH_4^+, pH, 1,1-dichloroethene, 1,2-dichloroethene cis, dichloromethane, tetrachloroethene, trichloroethene, vinyl chloride
81	Zvolen – Bučina – old depot	NH_4^+, COD_{Mn}, TOC, C_{10}-C_{40}, anthracene, benzo(a)pyrene, benzo(k)fluoranthene, fluoranthene, phenanthrene, chrysene, naphthalene
85	Bojná – landfill – part A (old)	As, Ba, B, Cl^-, NH_4^+, COD_{Mn}, TOC, conductivity
96	Banská Bystrica – former galvanizing shop LOBB	Mo, 1,2-dichloroethene cis, tetrachloroethene, trichloroethene
103	Rožňava – plume of chlorinated hydrocarbons at barracks	Cl^-, COD_{Mn}, tetrachloroethene, trichloroethene, vinyl chloride
106	Nové Zámky – Former Barracks of the Soviet Army – Novocentrum	1,2-dichloroethene cis, tetrachloroethene, trichloroethene, vinyl chloride
116	Hnúšťa – former SLZ	As, NH_4^+, COD_{Mn}, TOC, C_{10}-C_{40}, FNI, tetrachloroethene

Tab 4.5 – continue

ID	Environmental burden	Indicators exceeding the IT values
137	Trnovec nad Váhom – tailings Amerika I	B, Cl^-, F^-, NH_4^+, TOC, conductivity
142	Žiar nad Hronom – sludge field ZSNP	As, Mo, V, F^-, NH_4^+, COD_{Mn}, TOC, conductivity, pH
147	Smolenice – Chemolak	COD_{Mn}, TOC, C_{10}-C_{40}, FNI, benzene, ethylbenzene, toluene, xylene, styrene
156	Medzev – Strojsmalt	COD_{Mn}, TOC, C_{10}-C_{40}, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-c,d)pyrene
201	Bratislava – Ružinov – Čierny les	NH_4^+, COD_{Mn}, TOC, conductivity, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k) fluoranthene
203	Bratislava – Vrakuňa – landfill CHZJD	As, F^-, NH_4^+, NO_2^-, TOC, C_{10}-C_{40}, conductivity, FNI, benzene, ethylbenzene, toluene, xylene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, fluoranthene, phenanthrene, chrysene, naphthalene, pyrene, chlorobenzene, dichlorobenzene, trichlorobenzene, dichloromethane, tetrachloroethene, carbon tetrachloride, vinyl chloride, PCB
207	Smolník – pyrite ores	Al^{3+}, As, Co, Cu, Ni, Zn, conductivity, pH
213	Poproč – Petrova dolina Valley	Al^{3+}, As, Cd, Ni, Sb, Zn, pH
214	Jamník – barracks and airport Mokraď	COD_{Mn}, TOC, C_{10}-C_{40}, pH, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-c,d)pyrene
223	Martin – SNP barracks	C_{10}-C_{40}, NEL-IČ, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene
236	Prešov – airport	C_{10}-C_{40}, benzene, ethylbenzene, xylene
248	Čierna nad Tisou – transhipment station	Cl^-, C_{10}-C_{40}, non-polar extractable substances-UV, benzene, ethylbenzene, toluene, xylene, carbon tetrachloride
251	Žilina – eastern industrial zone	As, NH_4^+, benzene, ethylbenzene, toluene, xylene, styrene, 1,2-dichloroethene cis, 1,2-dichloroethene trans, dichloromethane, tetrachloroethene, carbon tetrachloride, trichloroethene, vinyl chloride
252	Bánovce nad Bebravou – Railway station	NH_4^+, TOC, 1,2-dichloroethene cis, tetrachloroethene, trichloroethene
253	Komárno – area after the Soviet Army	NH_4^+, TOC, C_{10}-C_{40}, benzene, xylene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, phenanthrene, indeno(1,2,3-c,d)pyrene, naphthalene, pyrene, tetrachloroethene
256	Rimavská Sobota – area after the Soviet Army	1,2-dichloroethene cis, tetrachloroethene, trichloroethene, vinyl chloride
259	Bratislava – Nové Mesto – Heating plant II	As, NH_4^+, TOC, conductivity, pH, FNI, benzene, chlorobenzene, dichlorobenzene, trichlorobenzene
289	Nové Mesto nad Váhom – locomotive depo	dichlorobenzene, vinyl chloride, PCB
293	Šurany – former ELITEX and STS	1,2-dichloroethene cis, tetrachloroethene, trichloroethene, vinyl chloride
294	Nováky – Military repair business	1,2-dichloroethene cis, trichloroethene
296	Prešov – former ZPA	Cl^-, conductivity, 1,2-dichloroethene cis, vinyl chloride
314	Krompachy – Kovohuty	Al^{3+}, As, Cd, Co, Cu, Hg, Ni, Pb, Sb, Zn, Cl^-, F^-, NH_4^+, TOC, conductivity, pH
338	Zvolen – army objects	Hg, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-c,d)pyrene
340	Brezno – Slovak Railways	TOC, C_{10}-C_{40}, non-polar extractable substances-IR, pH, benzo(a)pyrene, benzo(g,h,i) perylene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-c,d)pyrene

Notes:

PAH – polycyclic aromatic hydrocarbons, C_{10}-C_{40} – hydrocarbon index, PAL – anionic surfactants, FNI – phenol index, PCB – polychlorinated biphenyls

Tab. 4.6 Sites where no spread of contamination in groundwater or surface water has been detected (in brackets is the site identification number)

Udavské – Coating of bitumen blends (11)	Stropkov – Coating (16)
Nesluša – landfill (18)	Žiar nad Hronom – ZSNP – former factory area (45)
Bratislava – Slovak Gas Company (46)	Komárno – Slovak Gas Company (47)
Bardejov – electric station (52)	Haniska pri Košiciach – Slovak Gas Company (61)
Veterná Poruba – landfill (63)	Levice – mall Benzinol (69)
Piešťany – former tractor station (72)	Mád – lanfill (73)
Neded – former farm (QUEEN) (74)	Nitra – illegal release of oil substances at the sewage treatment (75)
Veľké Rovné – landfill (80)	Petrovice – Pšurnovice – playground (84)
Pernek – old mining works (86)	Hlboké nad Váhom – landfill II (88)
Dobšiná – landfill Bingarten (93)	Giraltovce – landfill (94)
Hlboké nad Váhom – landfill V (99)	Hlohovec – Šulekovo – landfill (100)
Čierne Kľačany – landfill (105)	Piešťany – oil refuelling station (107)
Zlaté Klasy – landfill (108)	Košice – Eastern Slovakia Engineering Works (110)
Tlmače – SES (141)	Levice – Levitex (129)
Šaľa – Duslo – nitric acid production (150)	Stará Turá –Chirana (145)
Udavské – landfill Janov dol (158)	Banská Belá – tailings Sedem žien (152)
Špačince – landfill (169)	Majcichov – landfill (166)
Hontianske Tesáre – agrochemical warehouse (209)	Bratislava – Central freight station (202)
Kráľova Lehota – landfill III (215)	Kysucké Nové Mesto – landfill at Secondary school (211)
Michalovce – city barracks (220)	Bielovce – pesticide storage (216)
Zemianske Kostoľany – army area (228)	Nové Zámky – traction power station (225)
Prešov – Sokolovské barracks (234)	Pezinok – Rudné bane – tailings (232)
Utekáč – former Clara glassworks (239)	Poprad – Railway station (237)
Čeľovce – pesticide storage (247)	Boldog – pesticide storage (243)
Nemšová – military unit (257)	Fačkov – landfill (250)
Nižná Polianka – stock of agrochemicals (260)	Bratislava – Ružinov – chemical dry cleaner (258)
Bytča – KK NEFT (266)	Bytča – former Slovak bus transportation (265)
Čadca – Slovak bus transportation (267)	Oščadnica – FRACHO (268)
Malé Dvorníky – pesticide storage (271)	Košarovce – Pastovník – fuel storage (273)
Ľubiša – farm area (274)	Udavské – railway station (275)
Dubnica nad Váhom – ZVS (277)	Liptovský Mikuláš – Locomotive depo (282)
Levice – Slovak Railways – surroundings of aboveground reservoirs (285)	Pohronský Ruskov – black oil industry of former sugar refinery (286)
Trenčianske Bohuslavice – Hydrostav (291)	Partizánske – ZDA – store of chemicals (295)
Poprad – fuel pump station (299)	Ľubochňa – forest area (302)
Soboš – stock of agrochemicals (310)	Stročín – former chemical cleaning (311)
Osadné – pesticide storage (315)	Strihovce – stock of chemicals of former farm Podvihorlat (316)
Trenčín – Air Repair Shops (317)	Trenčín – Slovak bus transportation (318)
Veľká Čalomija – pesticide storage (321)	Žilina – Trnové – fly ash dump (332)
Žilina – locomotive depo (333)	Hodruša-Hámre – Sandrik (334)
Bratislava – Devínska Nová Ves – quarry Srdce (339)	Plešivec – locomotive depo (342)
Dubová – stock of agrochemicals (309)	

Conclusion

Since 2012, the State Geological Institute of Dionýz Štúr has been carrying out tasks related to the monitoring of environmental burdens, currently at 309 sites. The aim of the work is to monitor the release of pollutants into the environment (especially groundwater and surface water) and to assess trends in the development of contamination.

Water sampling is performed on the basis of the procedures specified in the relevant Slovak technical standards (STN) of the STN EN ISO 5667 series. Physico-chemical properties are determined directly in the field: water temperature, air temperature, pH, specific electrolytic conductivity (at 25 ° C), dissolved oxygen content, percentage oxygen saturation, groundwater level (if relevant), or other indicators. A total of 15,000 to 20,000 field measurements of various indicators were implemented. Laboratory analyses of water are carried out in the Geoanalytical Laboratories of SGIDŠ (GALs), Regional Centre Spišská Nová Ves using standard methodological procedures.

In general, in the chemical composition of groundwater and surface water, the presence of calcium predominates in the case of macroelement cations, followed by sodium, magnesium and potassium. The anions are dominated by bicarbonates, followed by sulphates, chlorides and nitrates. The basic chemical composition of water is often changed in the areas of environmental burdens and is shifted from standard types (e.g. Ca-Mg-HCO_3 type) to those with a higher proportion of substances of secondary origin (Na^+, Cl^-, SO_4^{2-}). Pollution often occurs in areas of environmental burdens by increasing the values of total dissolved solids and conductivity.

Pollution from landfills as well as some other types of contamination is associated with the occurrence of high concentrations of boron, Cl^-, NH_4^+ and SO_4^{2-}. Due to the inclusion of mining sites in monitoring, the elevated contents of some trace inorganic elements, especially As, Cu, Zn, Cd, Sb occurred in waters. Among the organic substances, chlorinated hydrocarbons appear to be the most problematic within monitored environmental burdens, especially cis 1,2-dichloroethene, dichloromethane, tetrachloroethene, trichloroethene and chloroethene. Strong oil pollution caused by high hydrocarbon index (C_{10}-C_{40}) above the IT criterion (0.5 mg.l^{-1}) was found at 35 sites. Substances from the PAH group were monitored over ID or IT criteria only at the sites Zvolen – Bučina – Black Impregnation, Zvolen – Bučina – Old Depot and Medzev – Strojsmalt. Less problematic indicators in our monitored sites include some trace elements (Co, Cr, Cu, Hg, Mo, Pb, V), fluorides, nitrites, cyanides, phenols, chlorobenzenes, substances of BTEX and PCB.

From the point of view of physico-chemical indicators measured in situ in surface waters, a rather frequent phenomenon is the deteriorated quality of surface water caused by the deterioration of oxygen regime and occurrence of high values of conductivity and pH.

List of environmental burdens with a significant impact on the quality of groundwaters or surface waters from the point of view of contents that do not meet IT criteria according to the Directive of the Ministry of Environment of the Slovak Republic No. 1/2015-7, or the Government Regulations of the Slovak Republic no. 269/2010, includes 56 sites. These sites represent a wide range of economic activities that have been carried out in the past. In particular, various industrial activities, waste facilities and some mining sites are represented. Spread of contamination in groundwaters or surface waters was not found at the 81 EB sites.

The data obtained and the results of extensive monitoring contribute to the overall awareness of the effects of environmental burdens on the quality of groundwater or surface water. In other words, the public awareness of the risks associated with threats of EBs to human health or environment is improving.

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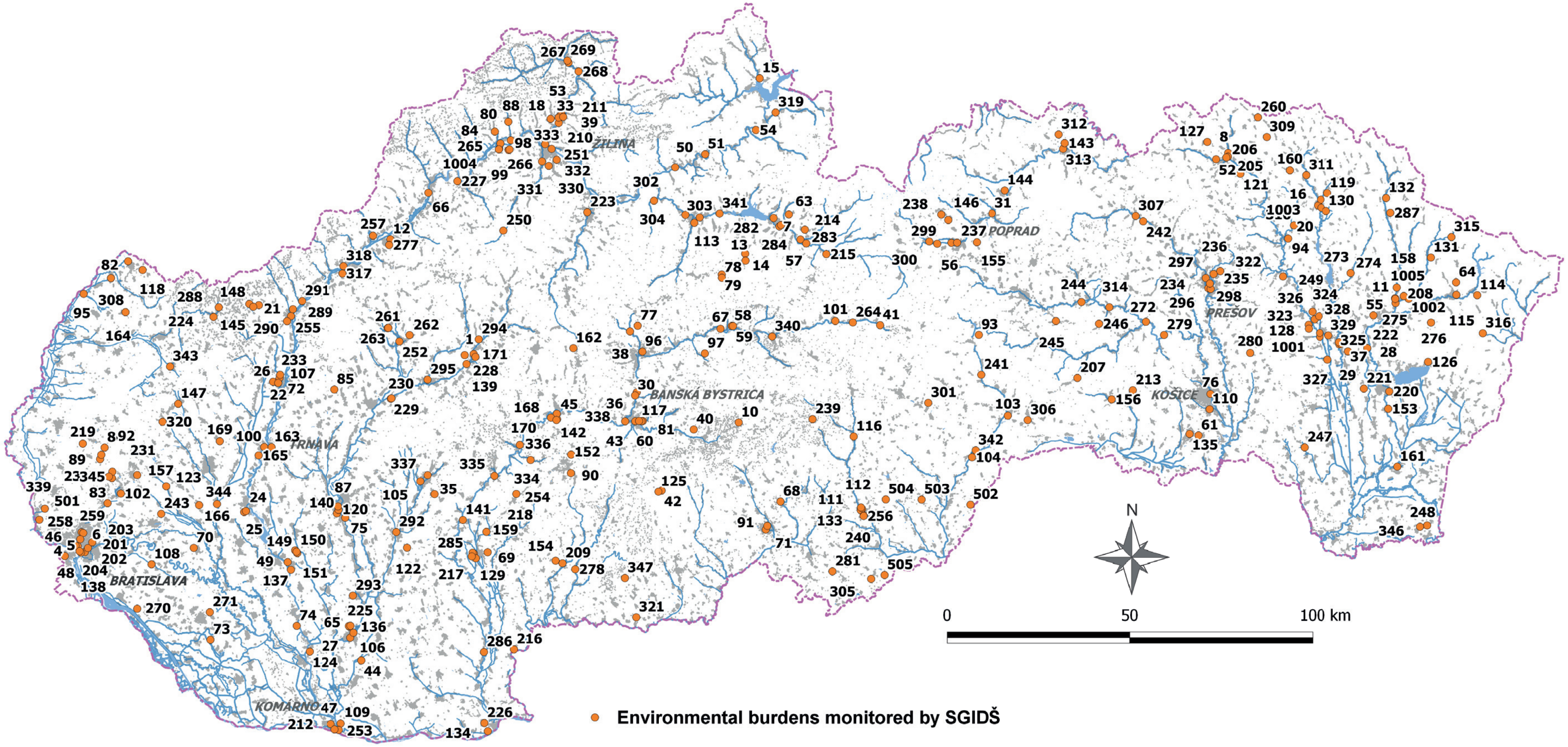
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Environmental burdens monitored by SGIDŠ

Annex

List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
1	Nováky – Chemical plants (2)	-463209	-1228520	SK/EZ/PD/626
4	Bratislava – Chemika (2)	-572101	-1280930	SK/EZ/B1/116
5	Bratislava – Gumon (2)	-571942	-1281047	SK/EZ/B2/122
6	Bratislava – Juraj Dimitrov chemical plants (2)	-570457	-1277293	SK/EZ/B3/138
7	Liptovský Mikuláš – Leather plants (2)	-379688	-1193613	SK/EZ/LM/406
8	Bardejov – Heavy engineering factory (2)	-256943	-1173508	SK/EZ/BJ/22
10	Hriňová - Heavy engineering factory (2)	-390812	-1247203	SK/EZ/DT/209
11	Udavské – Coating of bitumen blends (7)	-211218	-1213290	SK/EZ/HE/261
12	Dubnica nad Váhom – Heavy engineering factory (2)	-485976	-1197183	SK/EZ/IL/271
13	Lazisko – tailings of Liptovská Dúbrava (6)	-389017	-1201131	SK/EZ/LM/397
14	Dúbrava – galleries and heaps of Liptovská Dúbrava (6)	-388923	-1202967	SK/EZ/LM/390
15	Zubrohlava – sludge field – Heavy engineering factory Námestovo (2)	-385085	-1153122	SK/EZ/NO/541
16	Stropkov – Coating (7)	-232387	-1187919	SK/EZ/SP/917
18	Nesluša – landfill (1)	-442288	-1163974	SK/EZ/KM/321
20	Stropkov – TESLA (2)	-231488	-1188491	SK/EZ/SP/915
21	Nové Mesto nad Váhom – landfill Mnešice – Tušková (1)	-512735	-1216258	SK/EZ/NM/533
22	Piešťany – Chirana (2)	-516851	-1236436	SK/EZ/PN/676
24	Sereď – Nickel plant – landfill dump (2)	-525645	-1271459	SK/EZ/GA/222
25	Sereď – Nickel plant – former factory area (2)	-526082	-1271801	SK/EZ/GA/221
26	Piešťany – Tesla – contamination plume under the housing estate (2)	-518189	-1236114	SK/EZ/PN/675
27	Nové Zámky – Real H.M. – terminal (4)	-497372	-1302917	SK/EZ/NZ/588
28	Nižný Hrabovec – tailings Bukocel (2)	-226076	-1225790	SK/EZ/VT/1026
29	Poša – tailings of Chemko Strážske (2)	-224087	-1227840	SK/EZ/VT/103
30	Sliač – airport – south (4)	-419167	-1239838	SK/EZ/ZV/1128
31	Kežmarok – OKTAN (3)	-321490	-1190097	SK/EZ/KK/295
33	Kysucké Nové Mesto – NN Slovakia (2)	-440059	-1163866,4	SK/EZ/KM/315
35	Zlaté Moravce – Calex (2)	-475816	-1261651	SK/EZ/ZM/111
36	Zvolen – Bučina – black impregnation (2)	-417966	-1246810	SK/EZ/ZV/1132
37	Nižný Hrabovec – landfilll (1)	-226429	-1225920	SK/EZ/VT/1027
38	Banská Bystrica – Chemika (2)	-420550	-1222360	SK/EZ/BB/6
39	Kysucké Nové Mesto – KINEX-KLF (2)	-439621	-1163443	SK/EZ/KM/312
40	Detva – PPS Group (2)	-403084	-1249160	SK/EZ/DT/207
41	Pohorelá – Strojsmalt Holding (2)	-352179	-1220658	SK/EZ/BR/69
42	Lešť (military district) – garage yards (5)	-411828	-1265912	SK/EZ/ZV/1123
43	Zvolen – Bučina – white impregnation (2)	-417437	-1246916,8	SK/EZ/ZV/1131
44	Bajč – landfill (1)	-493881	-1312319	SK/EZ/KN/324
45	Žiar nad Hronom – ZSNP – former factory area (2)	-440551	-1244825	SK/EZ/ZH/1102
46	Bratislava – Slovak Gas Company – Votrubova street (3)	-571557	-1281119,9	SK/EZ/B2/131

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List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
47	Komárno – Slovak Gas Company (3)	-502019	-1329909	SK/EZ/KN/337
48	Bratislava – Matador – former factory area (2)	-575067	-1283587	SK/EZ/B5/161
49	Trnovec nad Váhom – RSTO landfill (1)	-514165	-1285472	SK/EZ/SA/804
50	Istebné – OFZ – slag piles (1)	-408170	-1177459	SK/EZ/DK/178
51	Medzibrodie nad Oravou – landfill Široká (1)	-399976	-1173867	SK/EZ/DK/180
52	Bardejov – electric station (2)	-260273	-1175202	SK/EZ/BJ/26
53	Kysucké Nové Mesto – KLF – Energetics (2)	-439176	-1162934	SK/EZ/KM/313
54	Nižná – OTF – sludge field Malá Orava (2)	-385880	-1167131	SK/EZ/TS/969
55	Myslina – old landfill (1)	-217156	-1218009	SK/EZ/HE/254
56	Svit – Chemosvit landfill (1)	-336559	-1198390	SK/EZ/PP/710
57	Podtureň – Žadovica landfill (1)	-373938	-1197231	SK/EZ/LM/417
58	Predajná – industrial landfill Predajná II. (1)	-392716	-1220871	SK/EZ/BR/74
59	Predajná – industrial landfill Predajná I. (1)	-392377	-1220881	SK/EZ/BR/73
60	Zvolen – Railway repair shops and machinery (4)	-418816	-1246965	SK/EZ/ZV/1135
61	Haniska – Slovak Gas Company (3)	-265049	-1250782	SK/EZ/KS/346
63	Veterná Poruba – landfill I. (1)	-377193	-1190354	SK/EZ/LM/424
64	Snina – old landfill (1)	-194572	-1208987	SK/EZ/SV/929
65	Nové Zámky – locomotive depo – diagnostic centre (4)	-496277	-1304462	SK/EZ/NZ/1789
66	Lednické Rovne – Podstránie landfill (1)	-475597	-1184428	SK/EZ/PU/727
67	Nemecká – Petrochema (2)	-395786	-1221633	SK/EZ/BR/67
68	Kalinovo – phenol pit (Žiaromat) (2)	-379412	-1268957	SK/EZ/PT/720
69	Levice – mall Benzinol (3)	-463502	-1282909	SK/EZ/LV/433
70	Veľké Úľany – landfill (1)	-539881	-1281637	SK/EZ/GA/230
71	Lučenec – Laundry and dry cleaning (7)	-383419	-1276561	SK/EZ/LC/371
72	Piešťany – former tractor station (7)	-517234	-1236230	SK/EZ/PN/674
73	Mad – landfill (1)	-535273	-1306724	SK/EZ/DS/194
74	Neded – former farm (QUEEN) (7)	-511712	-1302914	SK/EZ/SA/795
75	Nitra - illegal release of oil substances at the sewage treatment (Horné Krškany) (3)	-498320	-1273381	SK/EZ/NR/557
76	Košice – old gasworks (3)	-261808	-1239439	SK/EZ/K4/364
77	Špania Dolina – flotation treatment plant (6)	-418465	-1220789	SK/EZ/BB/17
78	Partizánska Ľupča – galleries and heaps Magurka (6)	-395402	-1207683	SK/EZ/LM/416
79	Partizánska Ľupča – tailings Magurka (6)	-395413	-1206794	SK/EZ/LM/414
80	Veľké Rovné – landfill I (1)	-453800	-1165018	SK/EZ/BY/113
81	Zvolen – Bučina – old depot (2)	-417080	-1246871	SK/EZ/ZV/1133
82	Skalica – former roller bearing plant (2)	-557783	-1203171	SK/EZ/SI/857
83	Svätý Jur – Brestová – landfill (1)	-563431	-1269360	SK/EZ/PK/665
84	Petrovice – Pšurnovice – playground (1)	-459565	-1168626	SK/EZ/BY/104
85	Bojná – landfill – part A (1)	-501153	-1238308	SK/EZ/TO/961

Annex

List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
86	Pernek – old mining works (6)	-564233	-1254939	SK/EZ/MA/467
87	Nitra – locomotive depo (Cargo) (4)	-500278	-1270600	SK/EZ/NR/559
88	Hlboké nad Váhom – landfill II (1)	-453692	-1172674	SK/EZ/BY/98
89	Pernek – Dolná Karol adit and heap (6)	-565534	-1257410	SK/EZ/MA/466
90	Banská Štiavnica – Lintich tailings (6)	-436679	-1261109	SK/EZ/BS/85
91	Lučenec – Marián Šustek – M Fruit (3)	-383003	-1275550	SK/EZ/LC/370
92	Pernek – Pavol adit and heap (6)	-564910	-1256585	SK/EZ/MA/468
93	Dobšiná – Bingarten landfill (1)	-325221	-1223290	SK/EZ/RV/779
94	Giraltovce – landfill (1)	-240595	-1196972	SK/EZ/SK/866
95	Unín – oil collection centre Cunín (3)	-569888	-1212086	SK/EZ/SI/863
96	Banská Bystrica – former galvanizing shop LOBB (2)	-417238	-1227977	SK/EZ/BB/1
97	Ľubietová – Podlipa (6)	-400245	-1228733	SK/EZ/BB/12
98	Kotešová – landfill (1)	-452408	-1169950	SK/EZ/BY/101
99	Hlboké nad Váhom – landfill V (under the birch) (1)	-453439	-1172571	SK/EZ/BY/97
100	Hlohovec – Šulekovo – landfill (1)	-520667	-1253880	SK/EZ/HC/243
101	Polomka – wood plant (2)	-364407	-1219524	SK/EZ/BR/71
102	Pezinok – stream Mahulianka (3)	-559765	-1266747	SK/EZ/PK/663
103	Rožňava – plume of chlorinated hydrocarbons at barracks (2)	-317114	-1245099	SK/EZ/RV/786
104	Plešivec – retention ponds (2)	-327072	-1256755	SK/EZ/RV/785
105	Čierne Kľačany – landfill (under the apple orchard) (1)	-473930	-1266908	SK/EZ/ZM/110
106	Nové Zámky – Former Barracks of the Soviet Army – Novocentrum (5)	-496923	-1306096	SK/EZ/NZ/585
107	Piešťany – oil refuelling station (3)	-516445	-1235095	SK/EZ/PN/678
108	Zlaté Klasy – landfill (1)	-551380	-1286106	SK/EZ/DS/206
109	Komárno – Madzagoš landfill (1)	-499605	-1329581	SK/EZ/KN/336
110	Košice – Eastern Slovakia Engineering Works (2)	-262042	-1243627	SK/EZ/K4/365
111	Rimavská Sobota – Slovak Sugar Factory (3)	-357466	-1271274	SK/EZ/RS/768
112	Rimavská Sobota – Gemer nákup (3)	-357128	-1271009	SK/EZ/RS/767
113	Ružomberok – brick factory (2)	-402964	-1192633	SK/EZ/RK/753
114	Stakčín – landfill (1)	-188832	-1212473	SK/EZ/SV/934
115	Belá nad Cirochou – landfill (1)	-198738	-1215177	SK/EZ/SV/922
116	Hnúšťa – former SLZ factory (2)	-359394	-1251072	SK/EZ/RS/756
117	Sliač – airport – pipeline (3)	-418771	-1239025	SK/EZ/ZV/1129
118	Skalica – landfill Zlatnícka dolina Valley (1)	-553827	-1205583	SK/EZ/SI/860
119	Chotča – landfill (1)	-229758	-1184529	SK/EZ/SP/912
120	Nitra – former fuel depots on the Novozámocká Road (3)	-500162	-1271223	SK/EZ/NR/553
121	Komárov – Lukavica landfill (1)	-253644	-1179249	SK/EZ/BJ/36
122	Vráble – landfill (part Židová) (1)	-481406	-1281569	SK/EZ/NR/567
123	Báhoň – landfill (1)	-547367	-1264735	SK/EZ/PK/640

Annex
List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
124	Kolárovo – landfill Pačérok (1)	-508142	-1309915	SK/EZ/KN/333
125	Lešť (military district) – main camp (5)	-412765	-1266218	SK/EZ/ZV/1124
126	Jovsa – landfill (1)	-202233	-1230702	SK/EZ/MI/485
127	Zlaté – landfill (1)	-262725	-1170369	SK/EZ/BJ/54
128	Čaklov – landfill (1)	-234915	-1221598	SK/EZ/VT/101
129	Levice – Levitex (2)	-462533	-1284520	SK/EZ/LV/432
130	Stropkov – poison cemetery Vojtovce (2)	-230063	-1189420	SK/EZ/SP/916
131	Papín – landfill (1)	-201424	-1202207	SK/EZ/HE/256
132	Krásny Brod – Monastýr landfill (1)	-213557	-1185619	SK/EZ/ML/503
133	Rimavská Sobota – Heavy engineering factory (2)	-357386	-1270577	SK/EZ/RS/766
134	Štúrovo – former JCP, asphalt and oil storage facility (2)	-459362	-1331690	SK/EZ/NZ/595
135	Košice – U.S. Steel (2)	-267680	-1250596	SK/EZ/K2/362
136	Nové Zámky – landfill (1)	-497055	-1303194	SK/EZ/NZ/587
137	Trnovec nad Váhom – tailings Amerika I (2)	-513322	-1287571	SK/EZ/SA/803
138	Bratislava – Malý Dunaj – influx object (2)	-570618	-1282824	SK/EZ/B2/123
139	Bystričany – ENO – temporary tailings (2)	-465166	-1231271	SK/EZ/PD/623
140	Nitra – Katruša landfill (1)	-500586	-1272164	SK/EZ/NR/560
141	Tlmače – SES (2)	-466212	-1273955	SK/EZ/LV/449
142	Žiar nad Hronom – ZSNP sludge field (2)	-442201	-1245889	SK/EZ/ZH/1097
143	Stará Ľubovňa – Skalka landfill (1)	-301601	-1170798	SK/EZ/SL/890
144	Spišská Belá – landfill (1)	-317951	-1183812	SK/EZ/KK/300
145	Stará Turá – Chirana (2)	-523608	-1215630	SK/EZ/NM/534
146	Veľký Slavkov – landfill Under the farm (1)	-333532	-1191871	SK/EZ/PP/716
147	Smolenice – Chemolak (2)	-544186	-1241935	SK/EZ/TT/981
148	Lubina – Palčekové landfill (1)	-522054	-1215173	SK/EZ/NM/526
149	Šaľa – Duslo – production of LAD and ammonium nitrate (2)	-511816	-1282606	SK/EZ/SA/798
150	Šaľa – Duslo – nitric acid production (2)	-511795	-1282628	SK/EZ/SA/797
151	Šaľa – Duslo – production of rubber chemicals (2)	-511805	-1282597	SK/EZ/SA/796
152	Banská Belá – Sedem žien tailings (6)	-436630	-1256014	SK/EZ/BS/79
153	Lastomír – landfill (1)	-213130	-1243545	SK/EZ/MI/486
154	Hontianske Tesáre – landfill (1)	-440933	-1285025	SK/EZ/KA/289
155	Žakovce – Úsvit landfill (1)	-325731	-1197977	SK/EZ/KK/310
156	Medzev – Strojsmalt (2)	-296955	-1239329	SK/EZ/KS/349
157	Modra – Hliny – landfill (1)	-555205	-1261599	SK/EZ/PK/645
158	Udavské – Janov dol landfill (1)	-208867	-1212736	SK/EZ/HE/262
159	Levice – landfill Levitex – Nixbrod (1)	-459394	-1282797	SK/EZ/LV/436
160	Hrabovčík – landfill (1)	-240102	-1178318	SK/EZ/SK/867
161	Vojany – EVO tailings (2)	-210611	-1259356	SK/EZ/MI/498

Annex
List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
162	Kremnické Bane – sheepfold (7)	-436017	-1226911	SK/EZ/ZH/1092
163	Hlohovec – industrial park (2)	-518594	-1254000	SK/EZ/HC/241
164	Unín – landfill (1)	-558302	-1217074	SK/EZ/SI/862
165	Hlohovec – Šulekovo – Fe-sludge (2)	-522099	-1256223	SK/EZ/HC/242
166	Majcichov – landfill (1)	-533491	-1269579	SK/EZ/TT/979
168	Žiar nad Hronom – ZSNP old industrial landfill (1)	-440436	-1246428	SK/EZ/ZH/1101
169	Špačince – landfill (1)	-532746	-1252365	SK/EZ/TT/982
170	Žiar nad Hronom – Horné Opatovce landfill (1)	-440582	-1246537	SK/EZ/ZH/1100
171	Zemianske Kostoľany – Xella (2)	-456973	-1229023	SK/EZ/PD/634
201	Bratislava – Ružinov – Čierny les (2)	-569573	-1282711	SK/EZ/B2/120
202	Bratislava – Ružinov – Central freight station (4)	-568721	-1281604	SK/EZ/B2/133
203	Bratislava – Vrakuňa – CHZJD landfill (1)	-567560	-1280050	SK/EZ/B2/136
204	Bratislava – Ružinov – Harbor (4)	-571007	-1282494	SK/EZ/B2/1904
205	Bardejov – JAS (2)	-257028	-1174540	SK/EZ/BJ/23
206	Bardejov – SNAHA (2)	-257452	-1174748	SK/EZ/BJ/24
207	Smolník – pyrite ores (6)	-298127	-1235055	SK/EZ/GL/237
208	Rovné – farm area (7)	-207513	-1213456	SK/EZ/HE/260
209	Hontianske Tesáre – agrochemical warehouse, poultry house (1)	-438981	-1285777	SK/EZ/KA/1742
210	Kysucké Nové Mesto – city landfill (1)	-440014	-1165330	SK/EZ/KM/314
211	Kysucké Nové Mesto – landfill at Secondary school (1)	-438796	-1163664	SK/EZ/KM/318
212	Komárno – Harčáš (1)	-500080	-1331330	SK/EZ/KN/335
213	Poproč – Petrova dolina Valley (6)	-282993	-1238424	SK/EZ/KS/353
214	Jamník – barracks and Mokraď airport (5)	-372730	-1194516	SK/EZ/LM/1909
215	Kráľova Lehota – landfill III (1)	-366863	-1201219	SK/EZ/LM/395
216	Bielovce – pesticide storage (1)	-452235	-1309306	SK/EZ/LV/428
217	Levice – laundry and dry cleaning (7)	-463753	-1283881	SK/EZ/LV/434
218	Nová Dedina – pesticide storage (1)	-459758	-1277179	SK/EZ/LV/438
219	Kuchyňa – airport (5)	-570133	-1253016	SK/EZ/MA/459
220	Michalovce – city barracks – autopark (5)	-212816	-1238783	SK/EZ/MI/1905
221	Pozdišovce – objects of former state material reserves (7)	-219751	-1238007	SK/EZ/MI/1913
222	Strážske – Chemko – waste channel (2)	-218806	-1226945	SK/EZ/MI/494
223	Martin – SNP barracks (5)	-432215	-1189765	SK/EZ/MT/512
224	Myjava – dump of galvanic sludge – Holičov vrch (1)	-534450	-1218380	SK/EZ/MY/521
225	Nové Zámky – traction power station (2)	-496879	-1302870	SK/EZ/NZ/1911
226	Štúrovo – main railway station (4)	-460313	-1329431	SK/EZ/NZ/598
227	Považská Bystrica – former Považské Engineering Works (2)	-467678	-1181284	SK/EZ/PB/1894
228	Zemianske Kostoľany – army area (5)	-465686	-1228829	SK/EZ/PD/636
229	Bošany – tannery dump I (2)	-485863	-1240740	SK/EZ/PE/1874

Annex
List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
230	Bošany – tannery dump II (2)	-485689	-1240633	SK/EZ/PE/637
231	Pezinok – ore mines and old mines (6)	-562068	-1260702	SK/EZ/PK/654
232	Pezinok – Rudné bane – tailings (6)	-562177	-1262448	SK/EZ/PK/656
233	Piešťany – barracks (5)	-516250	-1234200	SK/EZ/PN/677
234	Prešov – Sokolovské barracks (5)	-263085	-1207752	SK/EZ/PO/1898
235	Prešov – Duklianske barracks (5)	-261949	-1209260	SK/EZ/PO/1899
236	Prešov – airport (4)	-259116	-1205859	SK/EZ/PO/1907
237	Poprad – Railway station (4)	-331146	-1198085	SK/EZ/PP/1447
238	Vysoké Tatry – landfill Pod lesom (1)	-335471	-1190394	SK/EZ/PP/718
239	Utekáč – former Clara glassworks (2)	-370642	-1246340	SK/EZ/PT/1786
240	Rimavská Sobota – area after Soviet Army – Industrial park (5)	-356630	-1272708	SK/EZ/RS/1980
241	Nižná Slaná – mining plant and surroundings (6)	-324549	-1234194	SK/EZ/RV/784
242	Rožkovany – plume of chlorinated hydrocarbons (2)	-280162	-1192249	SK/EZ/SB/811
243	Boldog – pesticide storage (1)	-548730	-1272280	SK/EZ/SC/813
244	Markušovce – ore mining (6)	-297009	-1214298	SK/EZ/SN/898
245	Rudňany – ore mining and processing (6)	-303984	-1219510	SK/EZ/SN/899
246	Slovinky – ore mining and processing (6)	-292219	-1220252	SK/EZ/SN/900
247	Čeľovce – pesticide storage (1)	-236062	-1254059	SK/EZ/TV/989
248	Čierna nad Tisou – transshipment station (4)	-202487	-1275412	SK/EZ/TV/990
249	Merník – mercury mines (6)	-233904	-1216960	SK/EZ/VT/1024
250	Fačkov – landfill (1)	-455139	-1194777	SK/EZ/ZA/1053
251	Žilina – eastern industrial zone (2)	-441957	-1172400	SK/EZ/ZA/1070
252	Bánovce nad Bebravou – Railway station (4)	-483512	-1225084	SK/EZ/BN/57
253	Komárno – area abandoned by the Soviet Army (5)	-501240	-1331180	SK/EZ/KN/334
254	Pukanec – sludge dump Hampoch (1)	-451591	-1266828	SK/EZ/LV/441
255	Nové Mesto nad Váhom – area of military unit (5)	-514369	-1219550	SK/EZ/NM/530
256	Rimavská Sobota – area abandoned by the Soviet Army (5)	-356675	-1272870	SK/EZ/RS/1979
257	Nemšová – military unit (5)	-490718	-1196176	SK/EZ/TN/945
258	Bratislava – Ružinov – chemical dry cleaner (2)	-570830	-1279200	SK/EZ/B2/124
259	Bratislava – Nové Mesto – Heating plant II (2)	-570000	-1277500	SK/EZ/B3/140
260	Nižná Polianka – stock of agrochemicals (1)	-248833	-1163777	SK/EZ/BJ/44
261	Dežerice – VAB tailings (2)	-486730	-1221445	SK/EZ/BN/1926
262	Horné Naštice – fly ash dump (1)	-480740	-1223337	SK/EZ/BN/55
263	Dežerice – Veronika tailings (1)	-486542	-1221373	SK/EZ/BN/58
264	Závadka nad Hronom – Poľnospol Plus area (7)	-359640	-1219912	SK/EZ/BR/78
265	Bytča – former Slovak bus transportation (4)	-455928	-1170902	SK/EZ/BY/89
266	Bytča – KK NEFT (2)	-456278	-1172377	SK/EZ/BY/93
267	Čadca – Slovak bus transportation (4)	-437334	-1148853	SK/EZ/CA/168

Annex

List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
268	Oščadnica – FRACHO (2)	-434584	-1151254	SK/EZ/CA/173
269	Čadca – AVC – supermarket (2)	-437635	-1148298	SK/EZ/CA/1959
270	Báč – former STS (4)	-555278	-1298205	SK/EZ/DS/182
271	Malé Dvorníky – pesticide storage (1)	-535449	-1299144	SK/EZ/DS/195
272	Margecany – Locomotive depo, Cargo (4)	-279405	-1219708	SK/EZ/GL/1879
273	Košarovce – Pastovník – fuel storage (3)	-223352	-1206421	SK/EZ/HE/249
274	Ľubiša – farm area (7)	-210781	-1210384	SK/EZ/HE/251
275	Udavské – railway station (4)	-211094	-1214637	SK/EZ/HE/264
276	Valaškovce (military area) – washbasin (4)	-201425	-1219965	SK/EZ/HE/265
277	Dubnica nad Váhom – ZVS (2)	-486313	-1198723	SK/EZ/IL/272
278	Rykynčice – stock of old agrochemicals (1)	-435510	-1287415	SK/EZ/KA/291
279	Malá Lodina – dam Ružín (7)	-274456	-1223311	SK/EZ/KS/1998
280	Kecerovce – landfill Kecerovské Pekľany II (1)	-250949	-1228231	SK/EZ/KS/347
281	Šurice – former farm – pesticide storage (1)	-365207	-1287990	SK/EZ/LC/373
282	Liptovský Mikuláš – Locomotive depo, Cargo (4)	-381276	-1191351	SK/EZ/LM/1884
283	Liptovský Hrádok – Rettenmeier Tatra Timber (2)	-372362	-1198282	SK/EZ/LM/403
284	Liptovský Mikuláš – Velvetex (2)	-379246	-1193240	SK/EZ/LM/410
285	Levice – Slovak Railways – surroundings of aboveground reservoirs (2)	-463168	-1283167	SK/EZ/LV/437
286	Pohronský Ruskov – black oil industry of former sugar refinery (4)	-460424	-1310037	SK/EZ/LV/440
287	Čabiny – farm area (7)	-212529	-1189893	SK/EZ/ML/500
288	Myjava – former SAM (2)	-533013	-1215748	SK/EZ/MY/519
289	Nové Mesto nad Váhom – locomotive depo (4)	-513288	-1218158	SK/EZ/NM/532
290	Stará Turá – Drahý vrch landfill (1)	-524678	-1214826	SK/EZ/NM/535
291	Trenčianske Bohuslavice – Hydrostav (2)	-510241	-1214040	SK/EZ/NM/536
292	Vráble – Tesla (TESGAL) (2)	-484365	-1277245	SK/EZ/NR/566
293	Šurany – former ELITEX and STS (2)	-496222	-1294619	SK/EZ/NZ/605
294	Nováky – Military repair business (5)	-461850	-1224500	SK/EZ/PD/628
295	Partizánske – ZDA – store of chemicals (3)	-475827	-1235527	SK/EZ/PE/639
296	Prešov – former ZPA (2)	-262377	-1210538	SK/EZ/PO/689
297	Prešov – panel industry (2)	-260942	-1206646	SK/EZ/PO/690
298	Prešov – Solivary (2)	-261737	-1210750	SK/EZ/PO/693
299	Poprad – fuel pump station – Slovak bus transportation (3)	-332711	-1198112	SK/EZ/PP/700
300	Svit – fuel pump station (3)	-338754	-1197768	SK/EZ/PP/709
301	Magnezitovce – pesticide storage (1)	-339036	-1241871	SK/EZ/RA/733
302	Ľubochňa – forest area (7)	-414009	-1186614	SK/EZ/RK/742
303	Ružomberok – SCP area – SUPRA plant (2)	-401452	-1191184	SK/EZ/RK/747
304	Ružomberok – area TEXICOM – black oil management (2)	-405359	-1190485	SK/EZ/RK/748
305	Jestice – pesticide storage (1)	-354630	-1290045	SK/EZ/RS/762

Annex
List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
306	Krásnohorské Podhradie – sarcophagus under Kaplna (7)	-311699	-1246575	SK/EZ/RV/783
307	Lipany – ZVL area (2)	-282202	-1190783	SK/EZ/SB/808
308	Holíč – oil-fired boiler room (7)	-562446	-1207768	SK/EZ/SI/852
309	Dubová – stock of agrochemicals (1)	-246399	-1169149	SK/EZ/SK/864
310	Soboš – stock of agrochemicals (1)	-239002	-1193345	SK/EZ/SK/875
311	Stročín – former chemical cleaning (2)	-235623	-1179615	SK/EZ/SK/876
312	Jarabina – stock of agrochemicals (1)	-303251	-1168447	SK/EZ/SL/883
313	Stará Ľubovňa – SKRUTKÁREŇ – EXIM (2)	-302023	-1172391	SK/EZ/SL/891
314	Krompachy – Kovohuty (2)	-289402	-1215735	SK/EZ/SN/897
315	Osadné – pesticide storage (1)	-195862	-1196516	SK/EZ/SV/926
316	Strihovce – stock of chemicals of former farm Podvihorlat (1)	-187300	-1222870	SK/EZ/SV/935
317	Trenčín – Air Repair Shops (4)	-499067	-1206515	SK/EZ/TN/957
318	Trenčín – Slovak bus transportation (4)	-498796	-1204498	SK/EZ/TN/959
319	Trstená – former fuel storage Hámričky (3)	-380720	-1162440	SK/EZ/TS/973
320	Horné Orešany – Majdan – former chemical factory (2)	-548362	-1247043	SK/EZ/TT/977
321	Veľká Čalomija – pesticide storage (1)	-418840	-1300534	SK/EZ/VK/1003
322	Bystré – former brick factory TEMAKO (7)	-241976	-1207333	SK/EZ/VT/1007
323	Čaklov – former farm area (7)	-234973	-1220542	SK/EZ/VT/1009
324	Čičava – farm area (7)	-232083	-1218209	SK/EZ/VT/1011
325	Hencovce – Bukocel – extraction of black oil (2)	-226557	-1225335	SK/EZ/VT/1016
326	Komárany – stock of agrochemicals (1)	-233325	-1219033	SK/EZ/VT/1021
327	Sačurov – old steam mill (2)	-229710	-1230091	SK/EZ/VT/1032
328	Vranov nad Topľou – Čemerné – brick factory (2)	-231842	-1223851	SK/EZ/VT/1042
329	Vranov nad Topľou – Petrol station Dlhá ulica (3)	-229454	-1223467	SK/EZ/VT/1045
330	Rosina – fly ash dump – tailing pond (1)	-442726	-1177075	SK/EZ/ZA/1062
331	Žilina – ZVL (2)	-444569	-1175813	SK/EZ/ZA/1067
332	Žilina – Trnové – fly ash dump (2)	-440570	-1175360	SK/EZ/ZA/1840
333	Žilina – locomotive depo, Cargo (4)	-443734	-1171117	SK/EZ/ZA/1882
334	Hodruša-Hámre – Sandrik (2)	-447688	-1257504	SK/EZ/ZC/1074
335	Nová Baňa – former Technical Glass Works (2)	-457576	-1261832	SK/EZ/ZC/1077
336	Žarnovica – former Preglejka (2)	-450639	-1253362	SK/EZ/ZC/1081
337	Zlaté Moravce – locomotive depo (4)	-477786	-1263337	SK/EZ/ZM/1118
338	Zvolen – army objects (5)	-421876	-1246923	SK/EZ/ZV/1805
339	Bratislava – Devínska Nová Ves – quarry Srdce (2)	-582001	-1273892	SK/EZ/B4/147
340	Brezno – Slovak Railways (4)	-381656	-1223727	SK/EZ/BR/61
342	Plešivec – locomotive depo, Cargo (4)	-326080	-1254853	SK/EZ/RV/1858
343	Jablonica – depo (4)	-546305	-1231942	SK/EZ/SE/831
344	Voderady – landfill (1)	-538372	-1269889	SK/EZ/TT/1847

Annex

List of 309 monitored environmental burdens (at SGIDŠ)

ID	Environmental burden	Coord x_jtsk	Coord y_jtsk	ID Slovak Environmental Agency
346	Čierna nad Tisou – locomotive depo, Cargo (4)	-204427	-1275767	SK/EZ/TV/1861
501	Bratislava – Devínska Nová Ves – landfill at Volkswagen (1)	-580506	-1270858	SK/EZ/B4/152

Explanations:
1 – waste disposal facilities, 2 – industrial production, 3 – storage and distribution of goods, 4 – transportation, 5 – military base, 6 – mining of mineral resources, 7 – other

Instructions to authors

General instructions

The Editorial Board of the Slovak Geological Magazine accepts manuscripts in English language.

The Editorial Board accepts or refuses a manuscript with regard to the reviewers` opinions. The authors are informed about a refusal within 14 days after receiving the decision of the Editorial Board. Accepted manuscripts are prepared for a publication in an appropriate issue of the magazine. The author(s) and the publishers enter a contract establishing the rights and duties of both parties during editorial preparation and printing, until the time of a paper publishing. Simultaneously with article the editorial office must receive the corresponding author's proclamation that no part of the manuscript was already published and figures are original as well. Copied figures must be legalized by obtaining the copyright. The proclamation must contain the name of author (authors), title and the address of residence.

Text layout

The text should be arranged as follows: full name of the author(s); title of the paper, number of supplements (in brackets, below the title, e.g. 5 figs., 4 tabs.); key words - maximum 6 key words arranged successively from general to special terms; abstract (max. 300 words presenting principal results, without references); in a footnote of the first page, name of the author(s) as well as her/his/their professional or private address.

The extent of the article is limited to 30 manuscript pages including references, figures and explanations. Publishing of longer articles must be agreed by the Editorial Board.

The text of the paper should be logically divided. Text must be sectionalized by headlines, the position of the main headlines is in the centre of the page, associated headlines start from the left side of the page. The hierarchy of headings can contain maximum three levels (1 - highest level, 2 - lower, 3 - lowermost), being indicated by pencil at the particular heading. Text of the article has to contain the introduction, characterization (state) of investigated problem, used methodology, obtained data, discussion, conclusion and references.

The references in the text should be used preferably in parentheses. Names of cited authors in the text are written without first names or initials (e.g. Matula, 1969); the names of the co-authors are divided (e.g. Mišík & Sýkora, 1981). The name(s) is followed by a comma. If there are more authors, the first one, or the first two only are cited, adding et al. and publication year.

Mathematical and physical symbols of units, such as m, °C should be preceded by a space, e.g. 20 m, 50 °C, etc. In the case of % and ‰, the exemption shall be made: 10%, 2‰. SI units are preferred. Abbreviations of the units such as second, liter, etc. should be written without a period. Compass readings may be substitute by the abbreviations E, W, NW, SSE, etc. Brackets (parentheses) are to be indicated as should be printed, i.e. square brackets, parentheses or compound. Dashes should be typed as double hyphens. Please, use comma, as a 3-digit group separator (10,000) and decimal point, as separator of the fractional part of decimal number (0.1)

Text of the article must be sent to Editorial office printed in two copies with line spacing 2, as well as on CD. Please for using preferable MS Word editor for PC. Figs. and Tabs. must be delivered in digital form in separate files. Paragraphs are marked with 1 tab space from the left margin, or by a typographic symbol. Greek character in the text must be visualized in the text by its name [e.g. Ʊ (omega)]. Indices and exponents should be properly marked.

Figures and tables

The high quality of illustrations is required. Their aim is the most effective documenting and explaining the text. When drawing them by hand or computer their maximum width 81 mm (width of column) or 170 mm (width of page) must be taken into account. Properly adapted figure (dimensions of letters, thickness of lines) can be reproduced also in the scale 1: 1, but there is recommended to prepare figures in larger scale. The pen-drawn figures must be prepared by black ink using the template for figures. The minimum acceptable size of capitals and numbers in camera-ready figure is 2 mm. Maximum dimension of illustration in journal is 170 x 240 mm. Overlapping of illustrations should be avoided.

Figures compiled using the computer must be printed by high resolution laser printer (min. 300 DPI). For figures drawing the editorial office recommends the Corel Draw software. The very thin lines (hair lines) as well as automatic filling of objects are not allowed. The filling must consist from separately set objects. The raster-type filling of planes is either appropriate.

Each illustration including photographs must contain graphic (metric) scale. Grouped figures, e.g. photographs and diagrams must be compiled as one figure with separate parts designated a, b, c, etc. They are referred to as one picture.

Photographs must be sharp, preferably black & white, contrast, in the form of JPG or TIFF files having resolution of at least 600 DPI.

All figures must contain their number, description and name of author; in the case of maps and sketches an arrow indicating their orientation, and scale.

The explanations used for a series of several maps and profiles should correspond to that in the first figure. Description to figures should be inserted in the text on their proper place.

Each illustration and table must be referred in the text.

The high quality colour illustrations can be published after agreement by editorial office. The costs incurred will be charged to the account of the author (50 EUR for one page).

The Publisher reserves the right to return the graphic supplements back to author after language correction, resp. demand him to replace them by the higher quality ones.

Tables are submitted on separate page. Their layout is accepted in a size of up to A4. More widespread tables are not accepted.

Data are incorporated into table only when there is no possibility to incorporate them into text. The numbering of tables shall be gradual. Short explanation to a table should be included on the same sheet. If the text is longer, it should be typed on a separate sheet.

References

The list of references should only include the works cited in the text. The references are stated in alphanumeric order, with hanging indent in the second and following lines. The denotation "in press" can be used only in the cases of acceptance of reviewed version of article by editorial board. The denotation "personal information" can be cited only in the text (e.g. Kováčik, pers. information, 2008). When referring the data by other author not being the co-author of referred publication, in the text he is cited in the following form: (Gerda in Kubka, 1975), though in the list of literature is stated only Kubka J., 1975.

Examples of referring:

Book

Gazda, L. & Čech, M., 1988: Paleozoic of the Medzev nappe. Bratislava, Alfa, 155 p.

Journal

Vrba, P., 1989: Shear zones in the metapelite complexes. Mineralia Slov., 21, p. 135 –142.

Anniversary volume

Návesný, D., 1987: High-potassium rhyolites. In: Romanov, V. (ed.): Stratiform deposits of Gemericum. Spec. publ. Slov. Geol. Soc. Košice, p. 203 – 215.

Manuscript

Radvanský, F., Slivka, B., Viktor, J. & Srnka, T., 1985: Vein deposits of the Jedľovec nappe of Gemericum. Final report from the project SGR-geophysics. Manuscript-archive ŠGÚDŠ Spišská Nová Ves, 28 p.

Proofs

The authors are obliged to correct the errors, which are due to typing and technical arrangements. The first proof is sent to author(s). The second proof is provided only to the editorial office. It can be sent to authors upon request.

The proofs must be marked clearly and intelligibly, to avoid further errors and doubts. Common typographic symbols are to be used; their list and meaning will be provided by editorial office. Each used symbol must also appear on the margin of the text, if possible on the same line where the error occurred. The deadline and conditions for proof-reading are subject to the contract, which is governed by the Chairman of the Editorial Board.

Final remarks

These instructions are obligatory to all authors. Exceptions can be made by the Editorial Board or the Scientific Editor. Manuscripts not complying with these instructions shall be returned to the authors.

The Editorial Board reserves the right to publish preferentially invited manuscript and to assemble thematic volumes.

The manuscripts should be sent by e-mail to the address:
slovak.geological.magazine[at]geology.sk.

Contents

www.geology.sk/slovak-geological-magazine/