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).

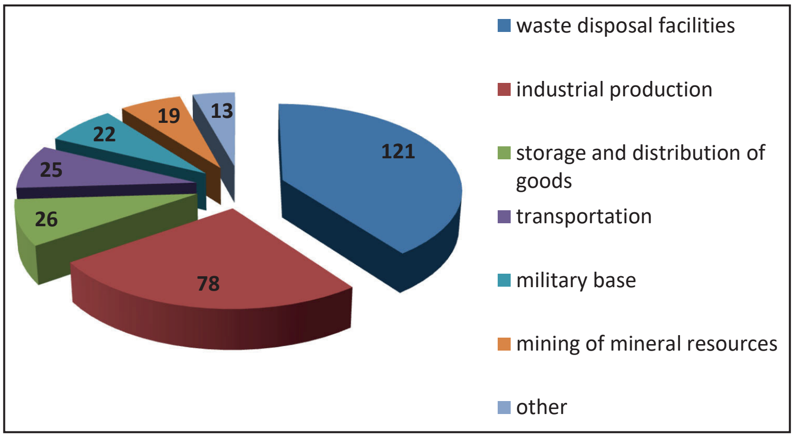

Fig. 1.1 Representation of economic activities at the assessed sites of environmental burdens

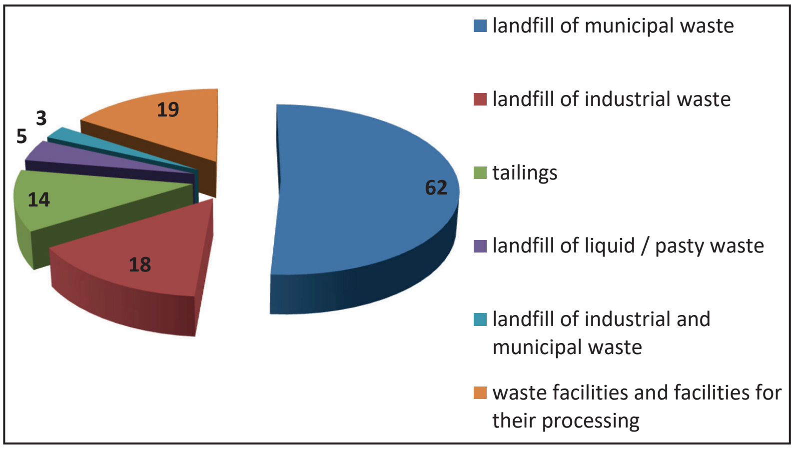

Fig. 1.2 Representation of economic activities related to waste management

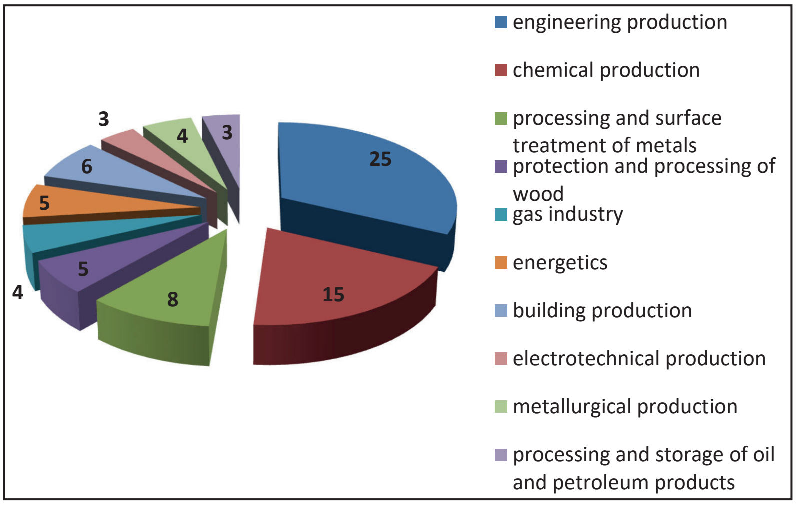

Fig. 1.3 Representation of economic activities related to industrial production

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.

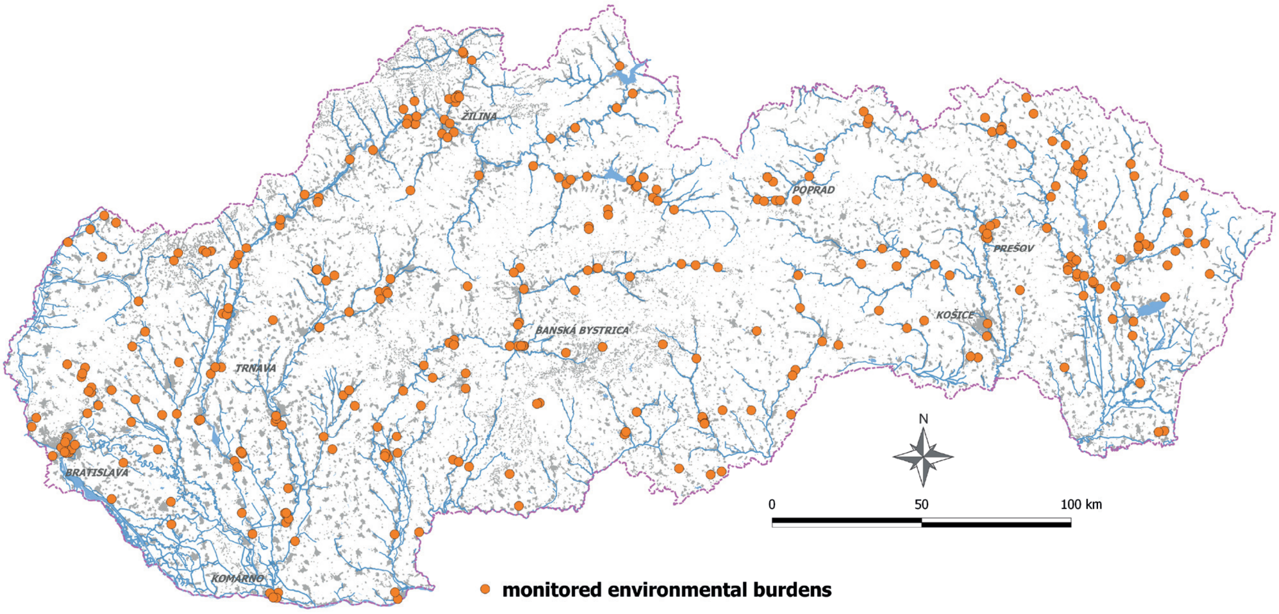

Fig. 1.4 Map of environmental burdens in Slovakia monitored by SGIDŠ

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.

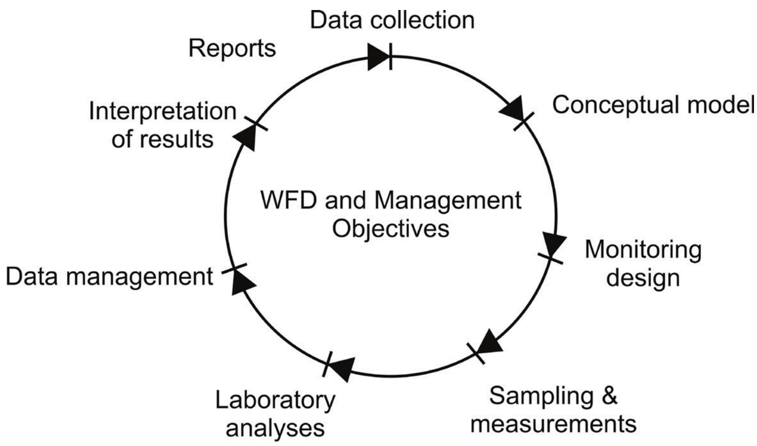

Fig. 1.5 Procedure of monitoring of environmental burdens (adapted according to the Common Implementation Strategy for the Water Framework Directive, Guideline 15 Groundwater Monitoring Guidelines)

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 geo-referenced 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

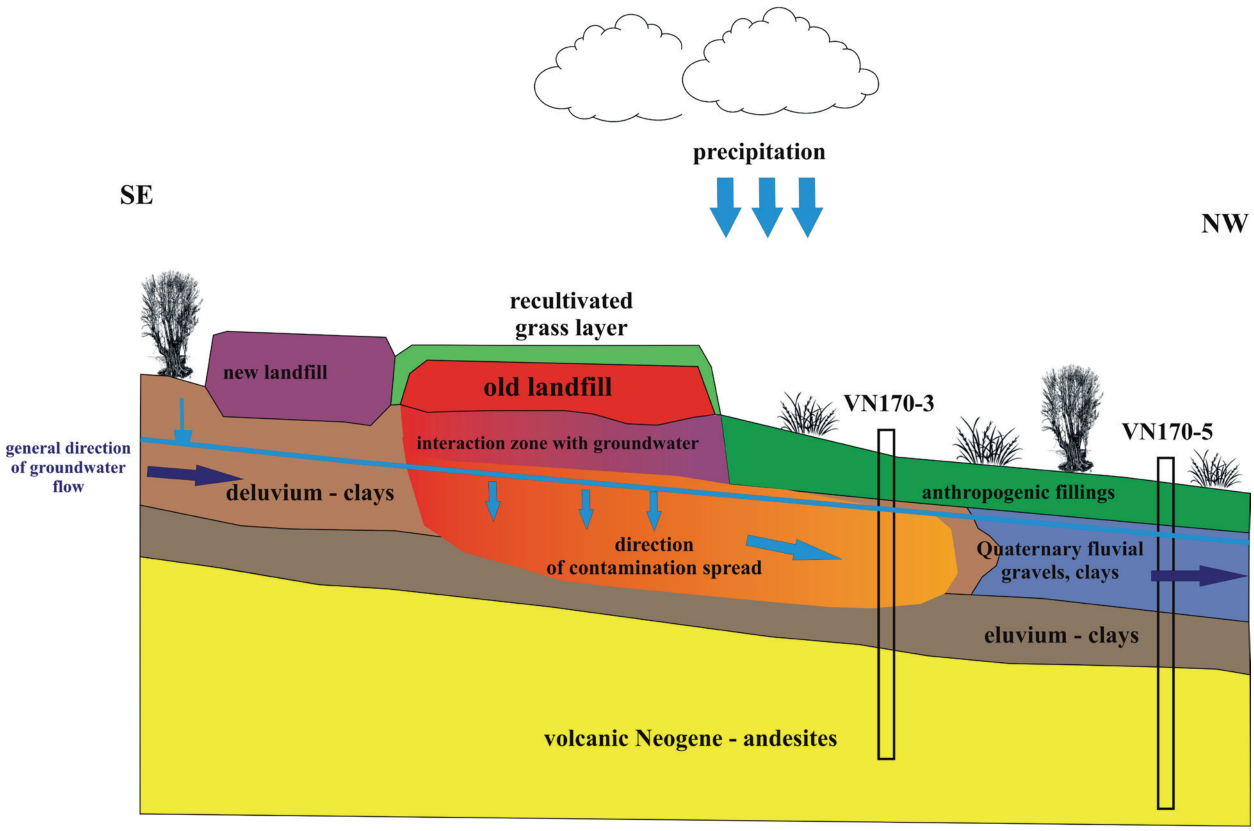

Fig. 1.6 Example of conceptual model – site Žiar nad Hronom – Horné Opatovce landfill

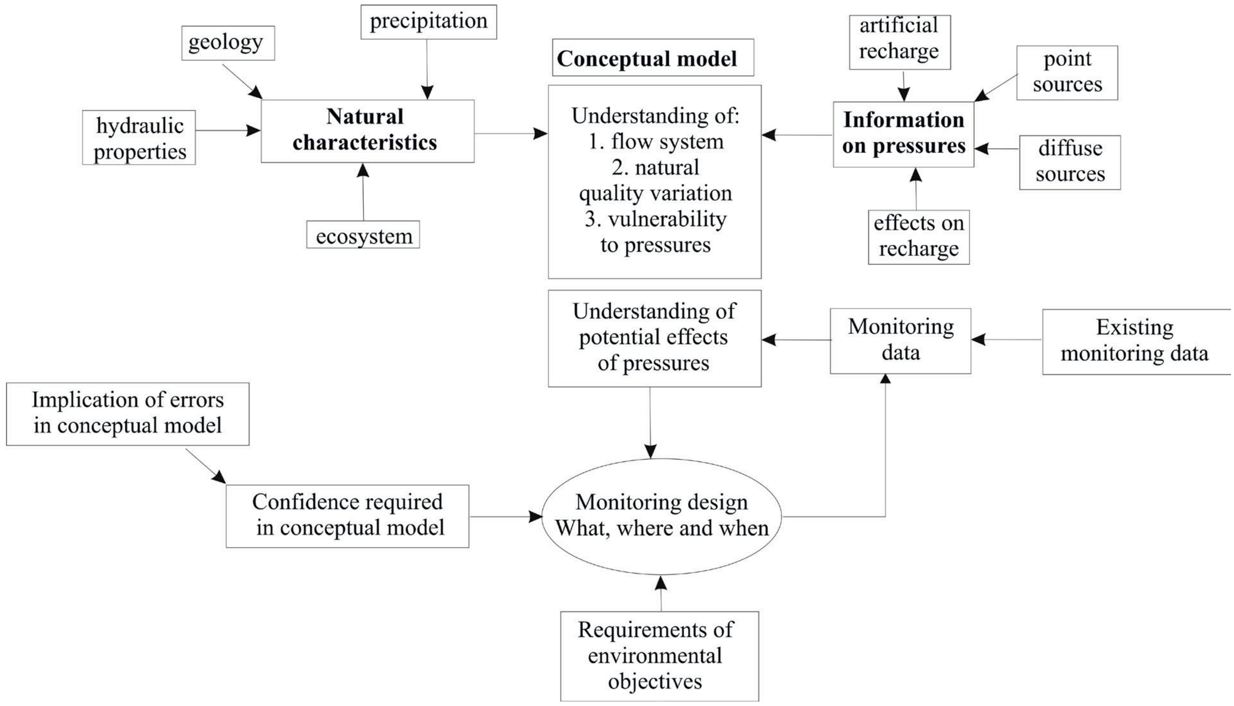

Fig. 1.7 Relationship between the conceptual model and the monitoring programme proposal (adapted according to the Common Implementation Strategy for the Water Framework Directive, Guideline 7 Monitoring)

(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.

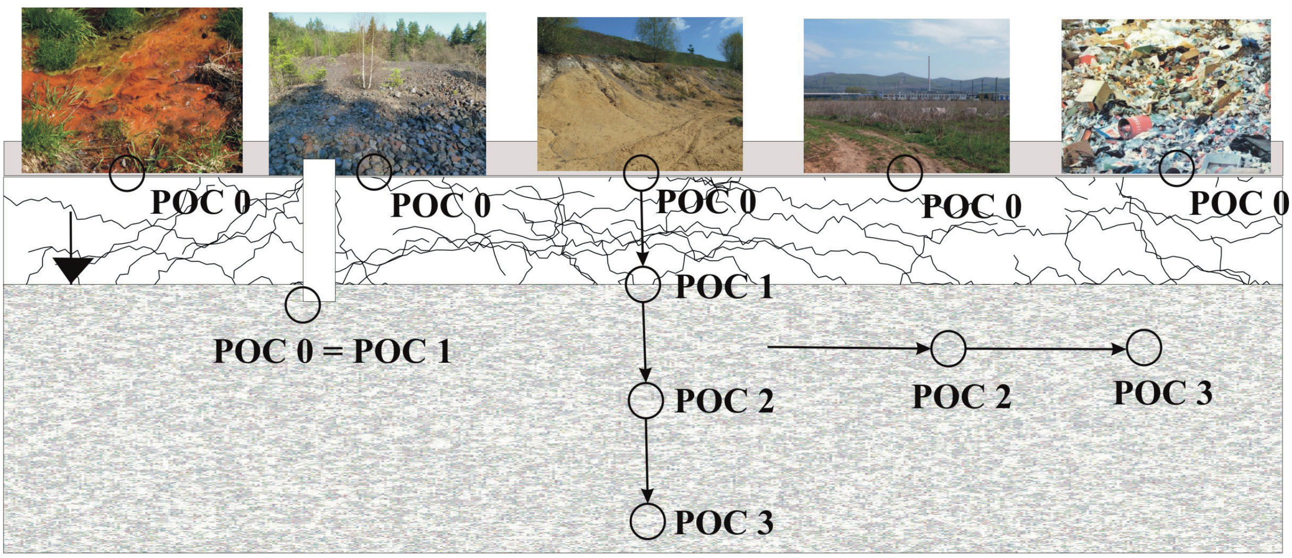

Fig. 1.8 Concept of points of compliance (modified according to the Common Implementation Strategy for the Water Framework Directive, Guideline 17 to prevent or limit direct and indirect inputs)

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

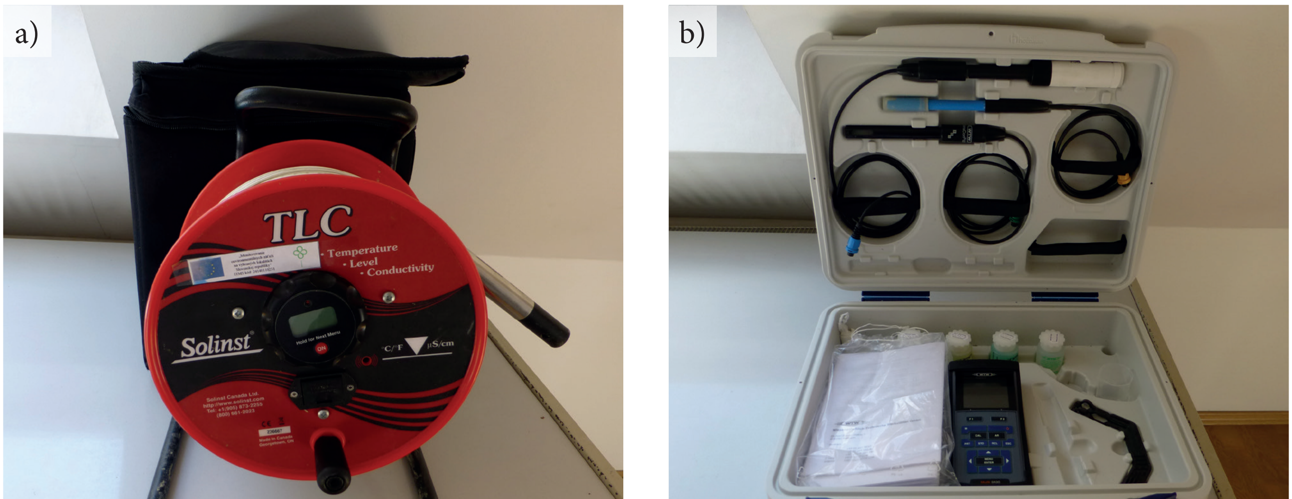

Fig. 1.9 Field measuring instruments: a) portable multimeter for measurement of pH, Eh, temperature, dissolved oxygen content and specific electrolytic conductivity, b) groundwater level meter enabling measurement of temperature and specific electrolytic conductivity of water

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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