Slovak Geol. Mag., 19, 1 (2019), 33 – 42

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.

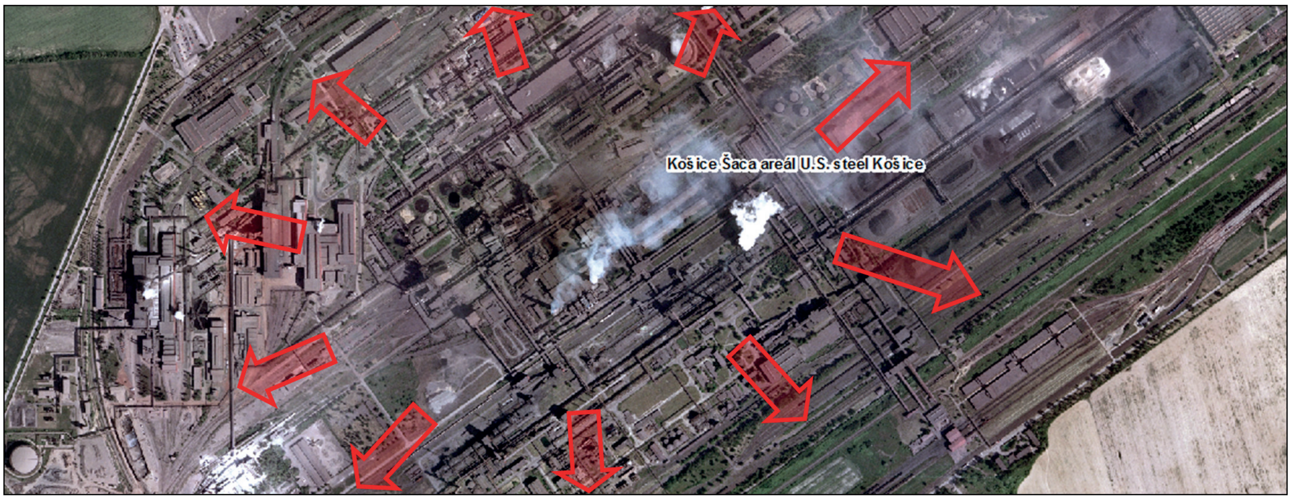

Fig. 3.1a Airborne image (2002)

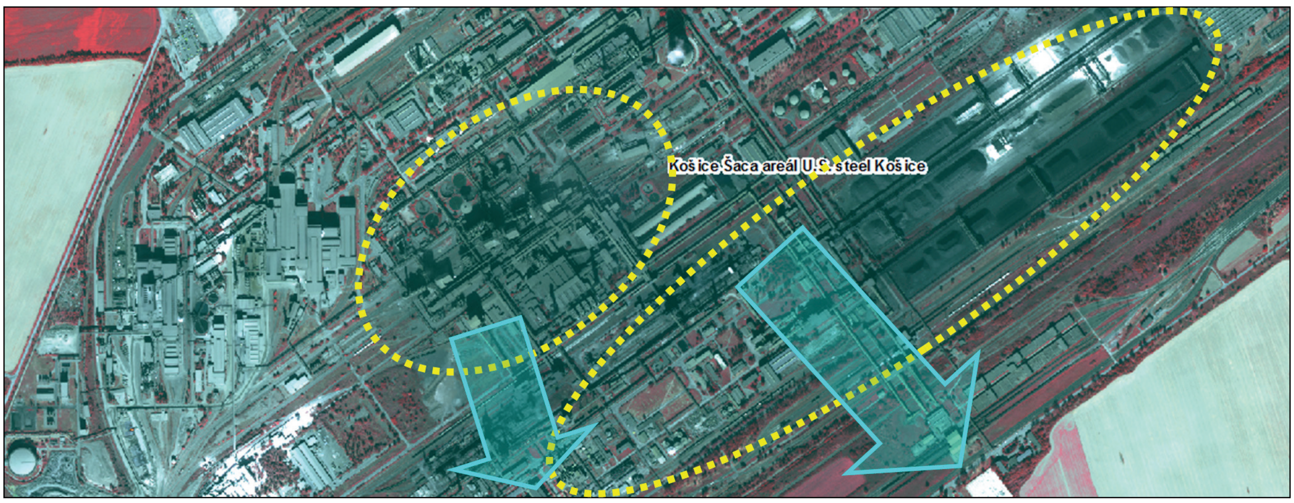

Fig. 3.1b Satellite image (2011), IR composition (WorldView-2: 7-5-3 bands)

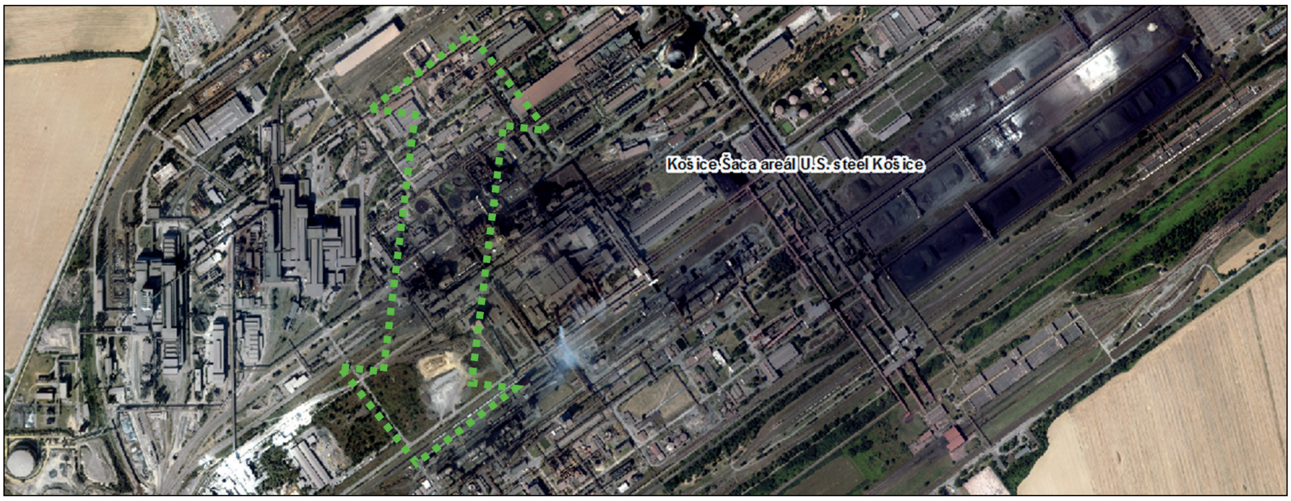

Fig. 3.1c Airborne image (2013)

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.

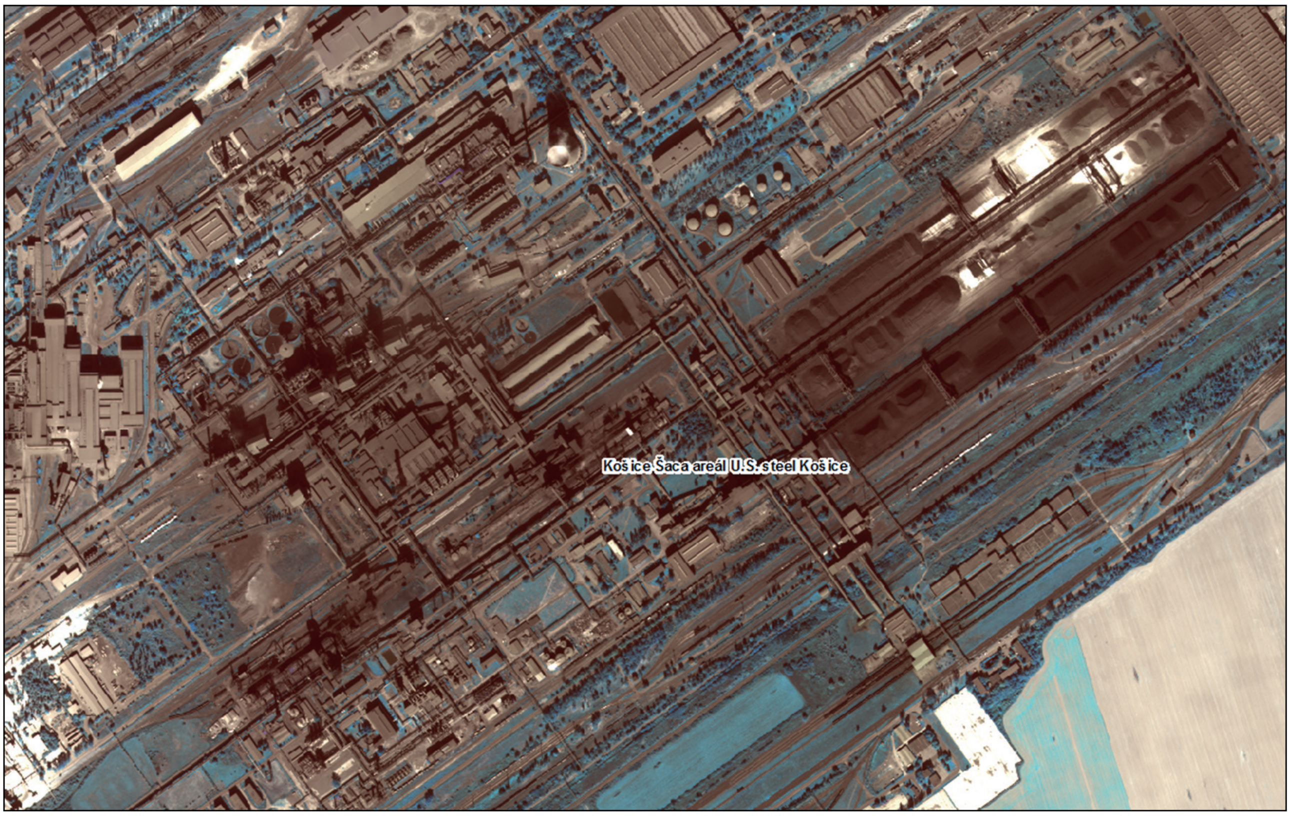

Fig. 3.2a Composition: "mining activity" (WorldView-2: 4-7-6 bands)

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

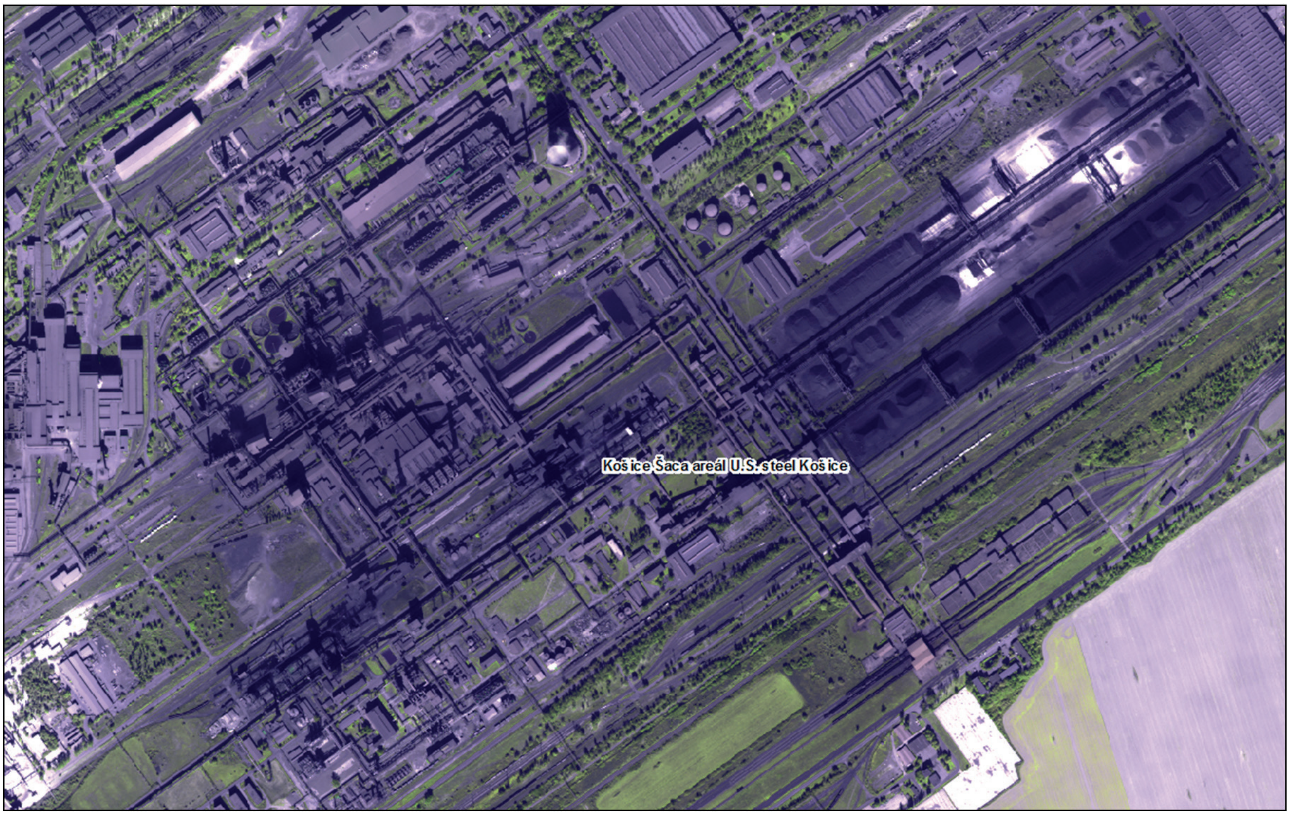

Fig. 3.2b Composition: "vegetation" (WorldView-2: 7-6-5 bands)

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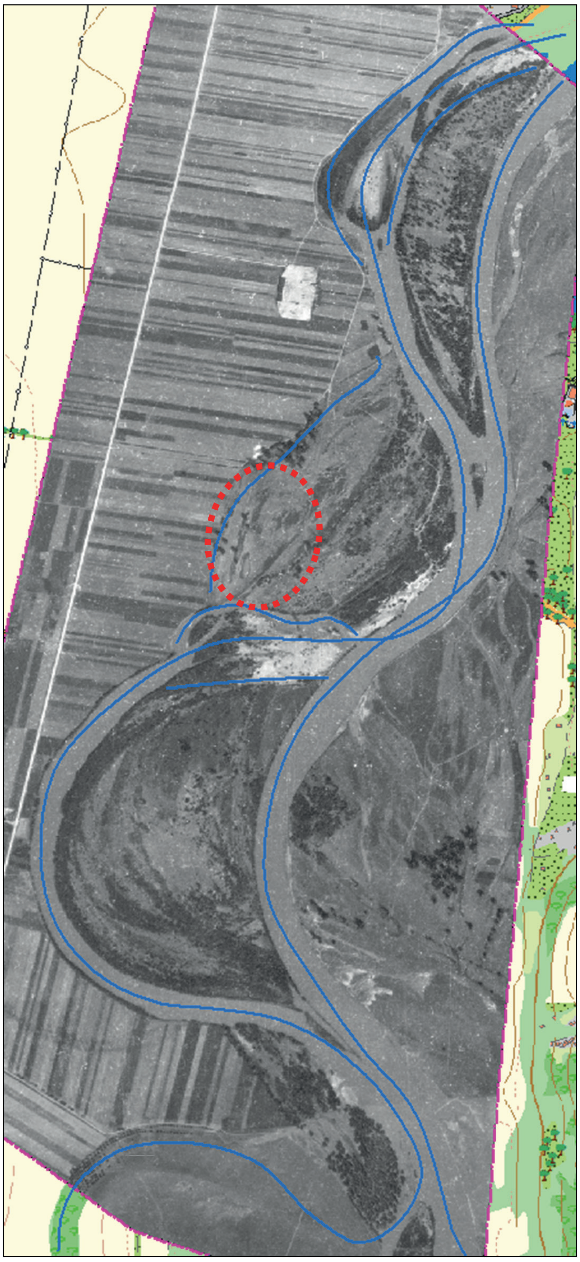
Fig. 3.3a Location of the future EB on a historical aerial photograph from 1950 (an old oxbow flows right through the site of the river Váh – marked with blue colour)



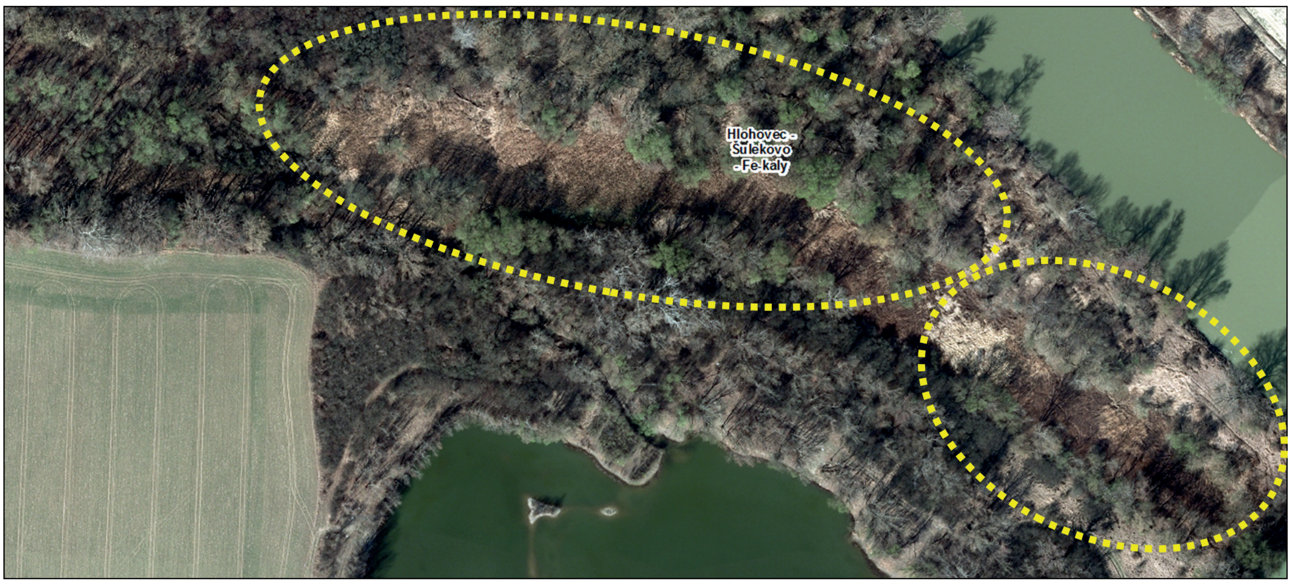


Fig. 3.3b Aerial image (2013), detail. Signs of pollution on vegetation in the vicinity of EB (brown, dried-up, burned vegetation)

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).

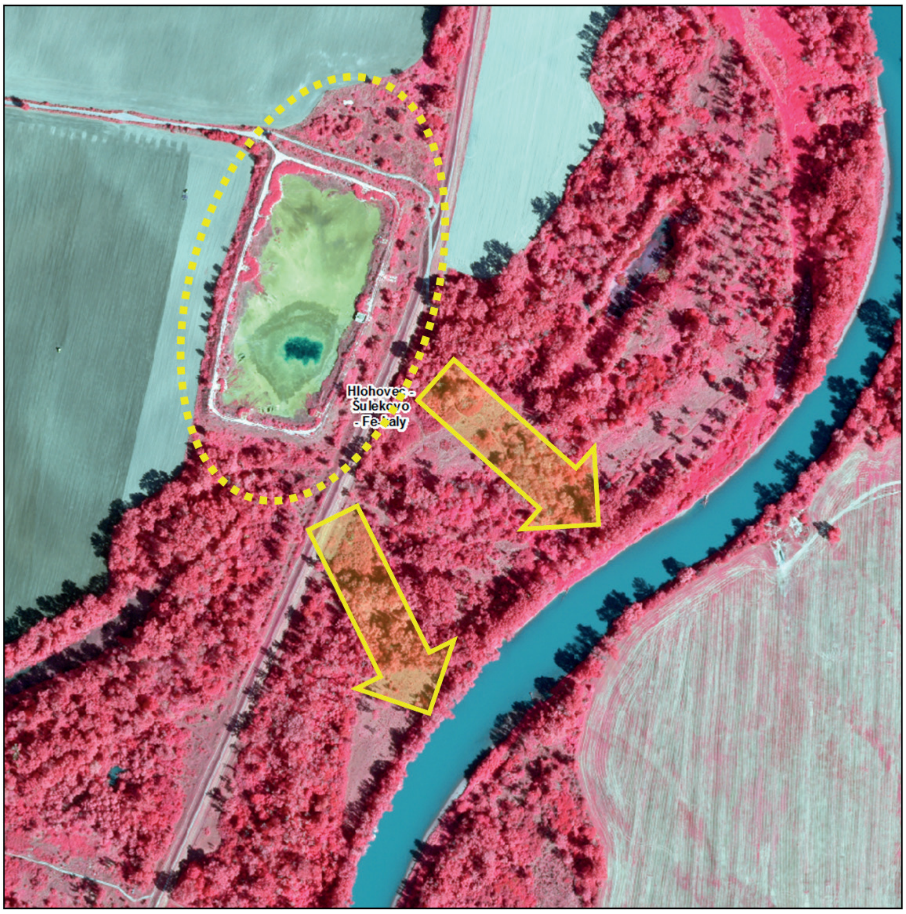


Fig. 3.4a Airborne image (2008) IR composition (4-3-2 bands)

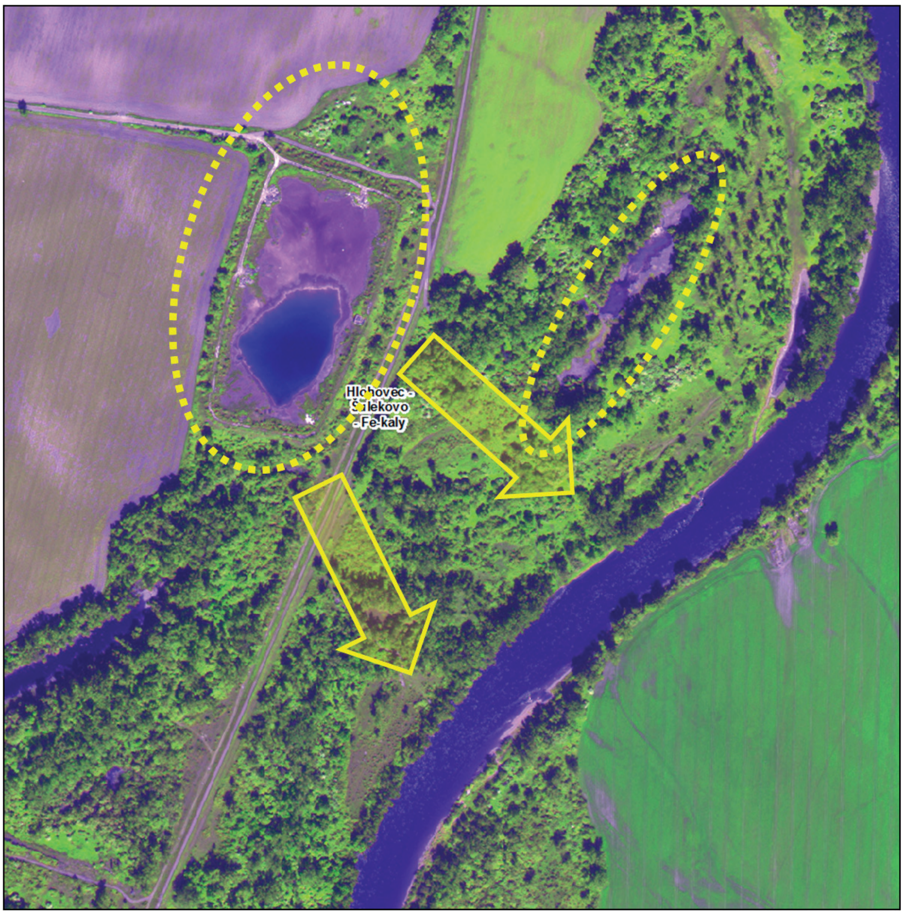


Fig. 3.4b Satellite image (2011) composition: "vegetation" (World-View-2:7-6-5 bands)

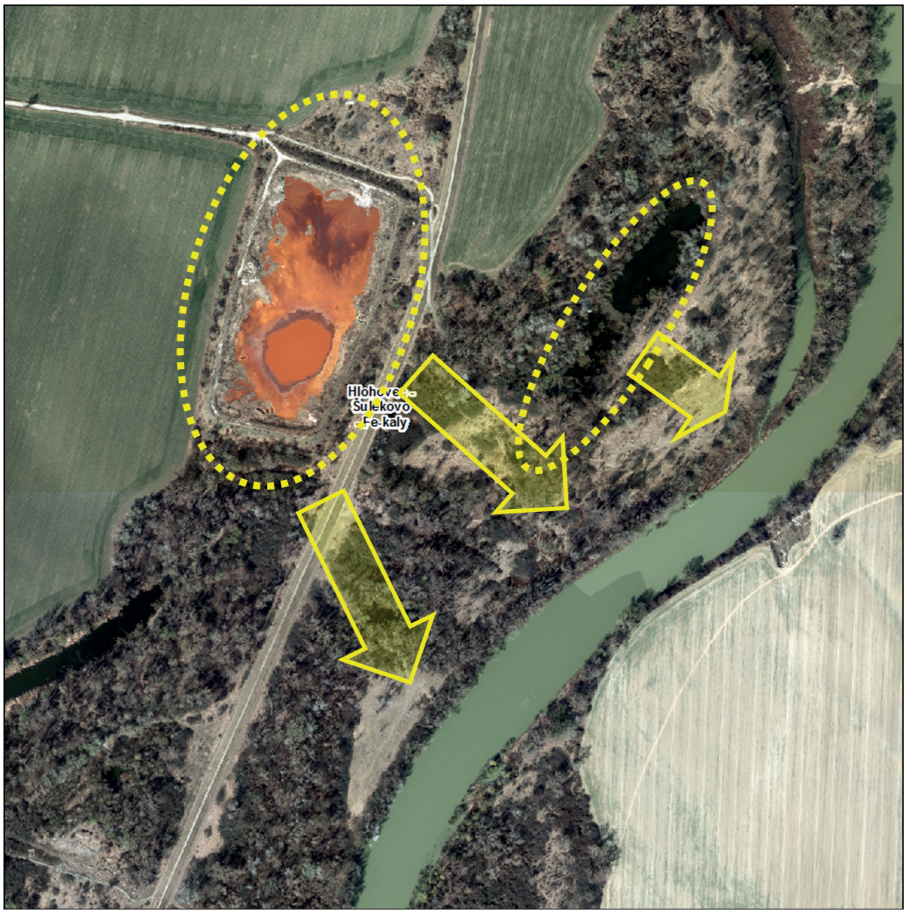


Fig. 3.4c Airborne image (2013), RGB

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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