Remote sensing data: A perfect tool for solving geological and geoenvironmental cross-border issues

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Abstract. Selected examples of the application of remote sensing data for geological and geoenvironmental investigations in the cross-border area are presented. These projects have been performed by the Polish Geological Institute in the international co-operation with the neighbouring countries partners, mainly geological surveys.

To define the land use and trace its changes in the Polish–Lithuanian cross-border area two Landsat satellite images have been acquired of 1979 and of 1992. It is noteworthy that in the period between 1979 and 1992 cultivated lands in Lithuania decreased by nearly 20%, while in the Polish part, cultivated land area increased by almost about 3%.

The Polish Geological Institute and the BGR (Geological Survey of Germany) started common studies in the Odra valley in the beginning of the 1990s. The multitemporal Landsat TM images, satellite radar data and aerial photos were widely used for mapping purposes.

By using satellite information (optical and microwave), local authorities, civil defense units and insurance companies received one more tool to monitor flood events in 1997 and to assess the damages.

In the regional scale, the satellite images could be also useful for landslide studies. With these images recognition of unstable terrain where slides occur could be possible. Such analysis is enriched when satellite images are applied together with DTM. Satellite images could be also useful for monitoring of land surface changes related to landslides activity. Several test sites for landslide risk monitoring have been established in the Carpathian Mountains in Poland, Slovakia and the Czech Republic

TerraFirma is one of the projects being run by the European Space Agency (ESA) under the GMES initiative. The Sosnowiec case study realized within this initiative and examples from other 17 European cities have indicated that the geological application of PSInSAR are evident for monitoring subsidence in relation to mining and tunnelling, climate change-driven shrink-swell ground conditions, landslides, volcanic and tectonic motions, and for assessing localised floods.

Key words: *remote sensing, geoenvironment, cross-border issues*

Implementing Action Item No. 19 of the 12th Annual Meeting of the COGEOENVIRONMENT (IUGS) has included the proposal and draft of the Terms of Reference of the Working Group International Borders — Geoenvironmental Concerns (IBC) prepared by Jonas Satkunas (Geological Survey of Lithuania), Marek Graniczny (Polish Geological Institute) and John Ridgway (British Geological Survey). The Terms of References was circulated among COGEO officers, on 3rd May 2002. According to voting results, during the COGEOENVIRONMENT annual meeting in Chiba (Japan), 18–21 November, 2002, the proposed IBC Working Group was unanimously approved. Marek Graniczny and Jonas Satkunas were approved as the Co-Chairs.

The aim of this initiative is to encourage and promote interdisciplinary cooperation across international borders (onshore and offshore) for the efficient application of geoscientific information in environmental planning, ecosystem monitoring and environmental impact assessment in cross-border areas, thus securing sustainable use of subsurface resources, the quality of the environment and the mitigation of geological hazards.

The following objectives are expected:

❏ to increase awareness of the relevance of geoscience to land use planning, subsurface resource management and sustainable development and management of cross-border areas;

❏ to inform planners, managers, developers, policy makers, lawyers and other appropriate groups concerned with cross-border areas of the importance of geoscience to their activities and interests;

❏ to develop practical and user-friendly geoscience-based approaches, techniques and models for use by all involved in cross-border environmental management issues;

❏ to inform or train geoscientists on the use of these approaches, techniques and models in relation to planning, land resource management and sustainable development of cross-border areas;

❏ to draw together the geoscientists of neighbouring countries where the current level of activities is different.

The importance of the newly created Working Group was confirmed during preparation to the International Geological Congress in Florence, August 2004, by the decision to organize a separate session G03.11 "International Borders — Geoenvironmental Concerns".

The above mentioned initiative is related to other enterprises undertaken with the European scope.

On 15th July, 2002, the European Space Agency (ESA) and the European Commission launched a consultation forum on satellite-based Global Monitoring for Environment and Security (GMES). By combining spaceborne, land-based and airborne technologies, GMES seeks to make better use of Europe's existing and planned capabilities and infrastructures and to develop mechanisms for improved collection and distribution of information. It therefore responds to growing concerns among policy makers about timely, free and independent access to information on the environment and security at the global, regional and local levels (Earth Observation Quarterly, 2003).

Such information are provided first of all by more and better and better satellite systems. These systems, usually placed at the polar orbits, are systematically collecting information regardless from of existing international borders and political systems. This was the reason to use such system for intelligence purposes, since the beginning of the 1960s (the CORONA programme in the United States, and similar programmes in the Soviet Union). However, since the end of the 1960s and the beginning of the 1970s the satellite systems like Gemini, Apollo or ERTS/Landsat started to be available for the non-military applications.

Geologists around the world are focusing most of their attention , in one way or another, on three major problems: accelerating and intensifying the exploration and assessment of resources, protecting and efficiently utilizing the environment, and identifying and minimizing the

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Fig. 1. The map of the main discontinuities and lineaments of the Kłodzko Valley superimposed at the DTM. For explanations of the labels of main discontinuities see text

effects of natural disasters. Satellite images have important applications in each of these problem areas (Reinemund, 1977).

In Poland, including the Polish Geological Institute, the satellite imagery appeared in the mid-1970s. Presently, they images contain an enormous set of data, from analogue materials like those by Landsat MSS and KOSMOS, through digital data from the next generations of satellites like: Landsat TM and Landsat ETM+, SPOT, ERS, IRS, to the high resolution systems, like IKONOS, Early Bird and interferometric processing of the radar data from ERS 1 and 2 and ENVISAT.

In this paper, selected examples of the application of remote sensing data for geological and geo-environmental investigations in the cross-border area will be are presented. These projects were developed by the Polish Geological Institute in the international co-operation with partners from the neighbouring countries, mainly their geological surveys.

Polish–Czech border

Tectonic studies

The direct association of commercial mineral deposits with geological features having a linear surface expression, such as faults and fracture zones, has long been known. Satellite images, displayed in appropriate formats, comprise a remarkably effective tool for recognizing and mapping several orders of such features in consi-

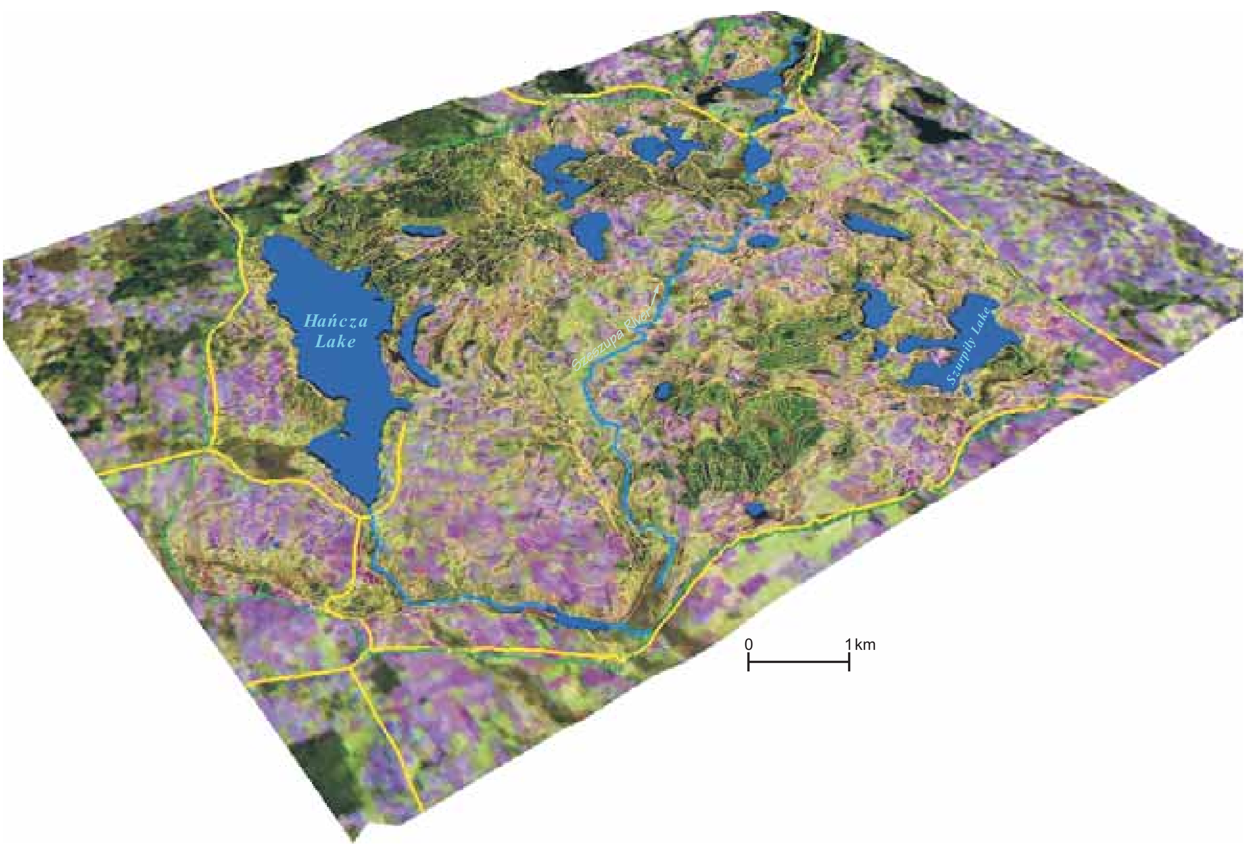

Fig. 2. Composition of the SPOT satellite image and DTM covering the area of the Suwałki Landscape Park (compiled by A. Janicka and Z. Kowalski)

derable detail. The data also allowed the definition of complex fracture-lineament systems over significantly large regions (Hodgson, 1977). The satellite systems were not designed specifically for such a job but, as it turns out, have several features which make them particularly well suited for the purpose, namely:

❑ Synoptic nature of the imagery.

❑ Temporal character (capability of recording the same scene many times).

❑ Very extensive areal coverage.

❑ Capability for digital enhancement of images, possibility to merge the data into the GIS format, Digital Elevation Models etc.

❑ Unrestricted availability (despite national border and political divisions) and relatively low cost of images.

The area of the Kłodzko Valley was subject of geological studies in Germany, Czech Republic and Poland since the end of 19th century. According to geological divisions, it belongs to the Middle Sudetes. The boundaries of the Sudetes Block are running mainly along the tectonic discontinuities which are named as frame dislocations. Among them the Marginal Sudetic Fault is considered as one of the most important. It was described by numerous authors, among them Cloos (1922a), Bedereke (1929), and Oberc (1955, 1960). It is clearly visible in the landscape as an morphological edge limiting the Middle Sudetes from north–east. The interior of the Sudetes Mts. is also fragmented by a dense and complicated system of faults of different age, constituting a complex mosaic structure (Cloos, 1922b).

The strike-slip character of the great Variscan faults was documented by the large-scale plumose systems, (Oberc, 1991). The main faults and the branching-off faults of lower order are prolonged upwards into the platform cover. The Main Sudetic Fault, the Tłumaczów–Sienna Fault and the Marginal Sudetic Fault were accepted as main faults. They all have dextral character. They mark-out three strike-slip blocks: the Fore-Sudetic Block, the Inter-Sudetic Block and the Outer-Sudetic Block; the plumose system of faults and strike-slip blocks of lower order formed on within the last. The Outer-Sudetic Block forms the main tectonic graben of Sudetes (Oberc, 1991).

The photogeological analysis of the remote sensing data from the Kłodzko Valley has covered diverse material such as aerial radar images, Landsat MSS and TM images and KOSMOS satellite images. The compiled lineament map shows a very complicated picture of the following systems directed: NW–SE, WNW–ESE, NNW–SSE, SSW–NNE and WSW–ENE. On the other hand, it enabled a detailed verification of some mapped and suggested faults (Fig. 1).

It was also possible to recognize several lineaments of a regional character:

❑ Bielawa–Biały Potok (NW–SE), corresponding to the fragment of the Marginal Sudetic Fault and continuing on the territory of the Czech Republic (1).

❑ “The Kłodzko System” (NW–SE) determined by two lineaments: Głuszyca Górna–Stara Morawa (2N) and Broumov–Sienna (2S).

❑ Jeleniów–Waliszów (WNW–ESE), corresponding to a known fault line (3).

❑ Wolany–Międzylesie (NNW–SSE), corresponding to known faults: Kamieńczyk and Jagodna, and continuing onto the Czech territory (4).

Fig. 3. The map showing the Lachowice landslide (compiled by Rączkowski in 1999) superimposed onto an IKONOS satellite image taken in 2002. The development of landslide activity and houses damages are clearly visible — indicated by arrows

❏ Starczów–Konradów (SSW–NNE); this system runs along the contact zone between The Kłodzko–Złoty Stok granitoid intrusion and the metamorphics of Śnieżnik and Lądek (5).

"The Kłodzko System" determined by two lineaments seems to be one of the most important tectonic features of the discussed area. It corresponds to the different geological boundaries (litostratigraphic, tectonic, etc.) and geophysical gradients (Graniczny, 1994). Besides that, 70% of the barite mineralization points of the Kłodzko Valley are located between the Marginal Sudetic Fault and the Kłodzko System. This and other facts indicate that the lineaments of the Kłodzko System are the surficial expression of the main faults. This statement is in agreement with the geological interpretation by Oberc (1991).

Polish–Lithuanian border

Geoenvironmental and geological studies

The topography of the Polish–Lithuanian cross-border area is characteristic of a glacial morainic upland in the northeast and glaciofluvial outwash plain in the south (Graniczny & Satkunas, 1997). The relief was formed during the glacial advance of the Late Weichselian maximum. The topographic altitudes vary between 130 and 298 m above sea level. The morainic upland is formed by marginal moraines, dead ice moraines, kames and kame terraces, eskers, and melt water erosion channels and other forms. During the deglaciation, glaciofluvial streams from the northern part of the upland flowed to the south and southwest forming the Augustów outwash plain, which is built of gravel and sand.

To define the land use and trace its changes in the Polish–Lithuanian cross-border area, two Landsat MSS satellite images have been acquired, of 1979 and of 1992. They have been processed using PCI (EASI/PACE) software at the Polish Geological Institute. Land use has been analysed by supervised and unsupervised methods (Atlas, 1997). According to satellite images classification, six land use classes have been distinguished: 1) coniferous forests, 2) mixed forests, 3) cultivated lands, 4) wetlands and pastures, 5) lakes, 6) nonclassified (Table 1).

The analysed satellite images have been taken in September, that of 1979 in the first and that of 1992 in the second decade of the month. The analysis revealed that considerably greater changes of land use in period 1979–1992 are noticeable in the Lithuanian territory. In 1979, due to intensive land cultivation by Soviet type collective farms, arable land occupied 48.5% of Lithuanian side of the cross-border area, while cultivated land occupied 28.8% of the area on the Polish side. It is noteworthy that in the period between 1979 and 1992, cultivated lands in Lithuania decreased by nearly 20%, while in the Polish part, cultivated land area increased by almost 3%. This dramatic change of land use in Lithuania has been obviously-caused by the collapse of the collective farms after regaining independence by Lithuania and the resulting economic transformation.

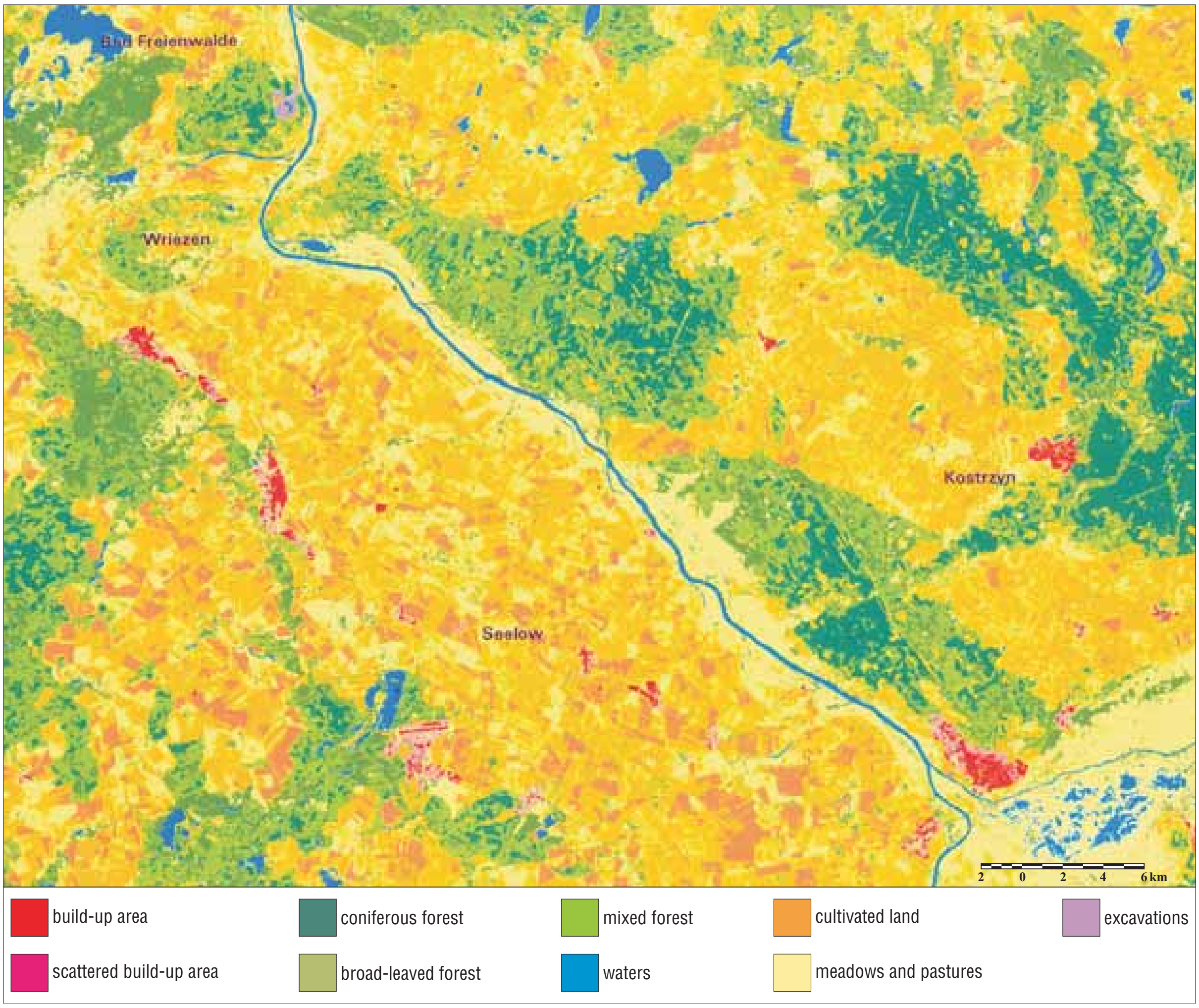

Fig. 4. Fragment of the land use map of the Odra River Valley and surroundings at the Polish and German territory

Landsat TM satellite images, recorded in 1987 have been applied for geological interpretation of the cross-border area (Graniczny, 2002). They were geometrically corrected (geocoding) and enhanced. The best enhancement of the geological and geomorphological features was observed at the two compositions: TM 542+5I and TM 451. It was found that combination of the enhanced composition with digital elevation model (DTM) gave even better results (Fig. 2).

The detailed analysis of the satellite images of the Suwałki area did not allow for direct identification of lithological boundaries due to the strong differentiation of geological conditions, vegetation cover, intensive agriculture and inadequate resolution of satellite images (30 m). However, valuable information was obtained on the basis of relief analysis. The negative forms of relief such as glacial tunnel valleys, kettle and exaration holes (for example, Szeszupa depression, Jeleniewo gully and Szelment gully) were clearly visible. It was also easy to identify bottoms of the river valleys and erosive valleys (Czarna Hańcza Valley). The belts of moraine hills near Wodziłki and Szurpiły are emphasized by their characteristic texture. It is also possible to differentiate sediments of the Suwałki esker and terraces within this esker (very difficult to identify during classical mapping), kames within the Szeszupa depression and dead ice moraines occurring near post glacial lakes. Moreover, between lakes Szelment and Hańcza, the lineaments were interpreted. They are surficial expression of the tectonic system, NW–SE oriented.

Table 1. Changes in land use during 1979–1992 according to interpreted satellite images (in %)

Class	Polish part		Lithuanian part	
	1979	**1992**	**1979**	**1992**
Coniferous forests	15.9	17.9	12.6	12.6
Mixed forests	17.0	15.1	9.6	12.8
Cultivated lands	28.8	31.3	48.5	28.5
Wetlands and pastures	26.3	26.4	14.1	35.9
Lakes	3.2	3.2	2.7	2.7
Nonclassified	8.8	6.1	12.5	7.5
Total	100.0	100.0	100.0	100.0

Polish–Slovakian–Czech border

Landslide studies

Major landslides in Poland are most characteristic of the Carpathian Mountains in the southeast of the country.

The location of areas at risk from major landslides is controlled by two main factors: the presence of slopes with a favourable geological structure, and high levels of precipitation. Both of these conditions are fulfilled in the case of the flysch Carpathians, consisting of interbedded shales and sandstones, deeply dissected by numerous valleys. The annual precipitation here reaches 800–1100 mm, sometimes concentrated in rainstorms. According to investigations carried out by the Polish Geological Institute, about 672 km^2, or 4% of the area of the Carpathians within Poland, has been in past, endangered by landslides or other forms of mass movement in the past. Current research indicate that the endangered area is even larger.

The temporal incidence of mass movement of the ground is strongly correlated with climate. During wet years,

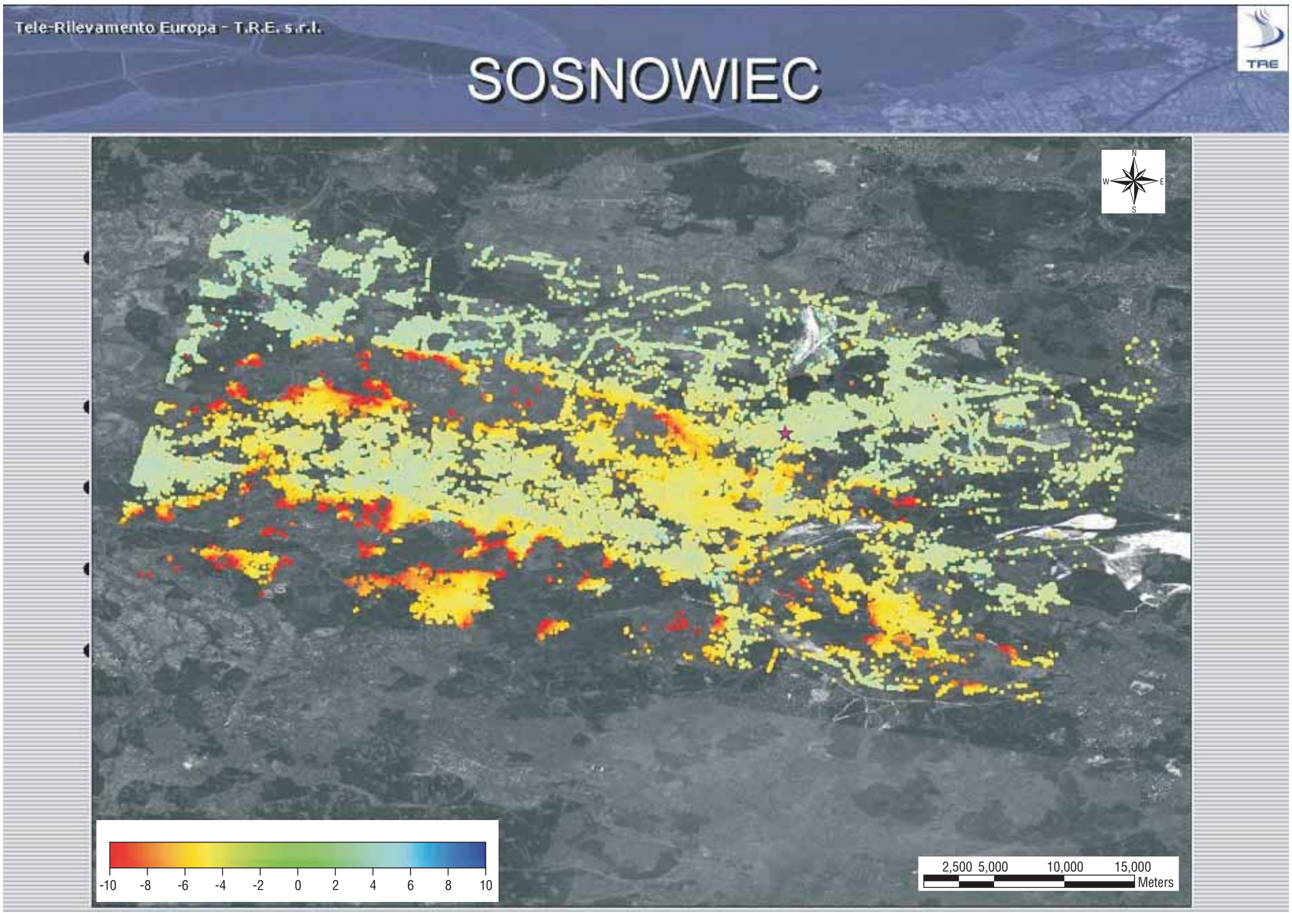

Fig. 5. PSInSAR map of the Sosnowiec city and its surroundings. Areas of maximum subsidence shown in red. The Sosnowiec cathedral used as a reference point is marked by a red star

or soon there after, an increased number of fresh or reactivated landslides is reported. Such situation took place after heavy rainstorms and floods in summer of 1997. Since that time numerous landslides in the Polish Carpathians were activated. Serious damages in houses and communication infrastructure were reported.

The Polish Geological Institute is presently developing a major project including registration of landslides in the Carpathians, monitoring their activity and making forecasts. These investigations will be financed by the European Investment Bank. The forecasts show the need of modification in the local plans of land use and development. Such plans are prepared in the smallest administration units — the communities ("gmina"). All available modern mapping technologies will be applied during realisation of the project, including remote sensing, GIS and GPS measurements.

Stereo pairs of aerial photos (B&W, normal colour and IR colour) have long been used to recognise slides and slide-prone terrain. Zones of previous sliding activity are easily identified in aerial photos by characteristic crescent scarps and the hummocky topography exhibited by the debris flow. It is obviously more difficult to identify areas that have a potential for sliding or slumping, but the characteristics may help to identify such zones. Because the key features in such cases are rather small, large-scale photos (about 1 : 10,000) have been found to be the most useful.

On the regional scale, the satellite images could be also useful for landslide studies. In these images, recognition of unstable terrain where slides occur could be possible. Such analysis is more reliable when satellite images are applied together with DTM. Satellite images could be also useful for monitoring of land surface changes related to landslides activity.

Such studies were performed for the area between Gorlice and Szymbark. Numerous landslides developed here, on the slopes of Maślana and Miejska mountains. The landslides were mapped during geological mapping made in the 1 : 50,000 scale.

The contours of landslides were superimposed onto the land use map, elaborated on the basis of the Landsat TM satellite image interpretation. It was found that about 50% of landslides are located within forested areas. It means that they constitute low hazard. In the next stage of the analysis, the mapped landslides were compared with DTM. The analysis revealed that most of the mapped landslide areas correspond to the mountain slopes of 8–10 degrees. This same analysis showed that the landslide areas are located beneath slopes inclined at 11–14 degrees. Another aspect of the analysis concerned location of landslides versus slope exposures. The above-presented digital analysis is very quick and very helpful for further field studies.

During the field work, GPS measurements are performed. Pathfinder ProXL instruments enable measurements with accuracy of half a metre, which is very good for mapping in the 1 : 10,000 scale. For the landslides monitoring purposes, the Aschtek GPS instrument is used, with accuracy of 1cm.

The new international project was established by the Polish Geological Institute, and to Czech and Slovak Geological Surveys, devoted to joint landslide studies in the Carpathians. Sometimes landslides cause "international" problems. For example, the landslide Osturnia located in the Podhale, just at the Polish–Slovakian border, was recognized in the 1960s. The escarpment of the landslide is situated on the Polish side of the border, but the mass movement the transported material stopped on the Slovakian side. The main aim of the project is integrating multi-thematic data collected during the field works and analysis of satellite images, aerial photos, digital elevation models, geophysical and meteorological data. Three test areas have been chosen; Lachowice in Poland, Vaculov Sedlo in the Czech Republic and Nova Bistrica in Slovakia (Fig. 3).

All landslides are localized at similar geological conditions — Magura Unit. The final outcome of the project will be preparation of a unified technology of the landslide monitoring and risk evaluation.

Polish–German border

Flood monitoring

Severe rains affects the Earth almost every year and cause floods, bringing serious damages to towns, roads, agriculture and to the environment in general, sometimes causing loss of human lifes.

Polish Geological Institute and BGR (Geological Survey of Germany) started common studies in the Odra valley on the beginning of the 1990s. The multitemporal Landsat TM images, satellite radar data and aerial photos were widely used for geological, geomorphological and land use mapping (Fig. 4).

In the first half of July 1997, heavy rains falling on the border areas between Poland, the Czech Republic, Austria and Slovakia, swelled the water courses and caused floods in the southern part of this region. Within a 10-day period, over 100 people died in Poland and in the Czech Republic.

On 15th July, ERS-2 SAR data revealed consistent floods near Wrocław on the Odra River and westwards, along the river course. The extent of the flooding along the Odra River was revealed by ERS-2 SAR multitemporal images on 18th July. Additional SAR data, collected from ERS-2 on 21st July, provided up-to-date information on the event. The flooding along the Odra reached the border between Germany and Poland with a high water pressure that seriously threatened the resistance of a 160-km dike along the Odra near Frankfurt. Threatened zones of the dike could be identified at the Landsat TM data, registered on 22nd July. On 23rd July, the 160-km dike collapsed. Two days later, the residents in the Frankfurt am Oder neighbourhood had to be evacuated. In the Czech Republic, thousand of homes were destroyed and thousand of acres of farmlands badly affected. In Poland, over 149 villages were submerged and almost as many were threatened by new floods. On 26th July, about 15,000 citizens had to leave the town of Słubice on the Odra. The Polish side of the Odra was more in danger than the German side, because of the height difference between the two river banks (1–3 m lower in Poland). In the night of 27th–28th July, the water level in Frankfurt reached a record height of 6.75 m. The situation improved during the second half of August. Waters retreated, thus reducing the risk of further dike cracks, with the exception of the Oderbruck region. Here, the high water level was still threatening villages and farmlands.

By using satellite information (optical and microwave), local authorities, civil protection entities and insurance and re-insurance companies are offered one more tool to monitor flood events and to assess damages. Furthermore, by combining the satellite information with topographic data (DTM), geological and hydrological data, even more end-user-oriented products can be obtained for direct utilization application by administrators in charge of risk management and hazard prevention.

TerraFirma Project

Subsidence monitoring. TerraFirma is one of the 10 GMES Services Elements projects being run by the European Space Agency (ESA) under the GMES initiative. The project is establishing a "pan-European ground motion hazard information service in support of policies aimed at protecting the citizen”. Ground motion hazards include subsidence in all its forms, landslides and the effects of seismicity, though initially, and to be immediately operational, the focus is on urban subsidence. The project initiator, and Coordinator is NPA Satellite Mapping of UK. The project started in early 2003 with a core of National Geological Surveys including the UK, France and the Netherlands, but has now expanded with the addition of Norway, Poland (Polish Geological Institute — since summer 2003), Israel, Ireland, Greece and Germany. The negotiations are underway with other countries. The project remains open to the participation of other major civil engineering organizations, too.

This large-scale project uses the data collected by European radar satellites (ERS-1, ERS-2 and ENVISAT) in a process called Synthetic Aperture Radar Interferometry, or InSAR for short. InSAR can cover whole cities and regions, and because an archive exists of “repeat” satellite data, measurements can be provided even for the last twelve years.

InSAR has been available to us for since over a decade, providing ground deformation data at centimetre resolution (Perski, 2000). In the past two years, new ways of processing satellite radar images have been invented, that allow ground movements to be mapped and monitored to better than 1 mm per year. This process is called Permanent Scatter Synthetic Aperture Radar Interferometry, or PSInSAR for short. The technique depends on the existence of radar scatters which consistently reflect signals from successive satellite passes. This means it works best in urban and arid conditions where vegetation cannot interfere with the coherence. Several tens of images taken during last twelve years (1992 — launching of the ERS-1 satellite) can be processed simultaneously with the PSInSAR technology. Images are processed by the Italian company TRE-TELE-RILEVAMENTO EUROPA in Milano.

The TerraFirma project is split into three stages (0–2, 2–5, 5–10 years). The first stage, which commenced in early 2003, was focused on consolidation of the InSAR- based services that already exist, plus expansion of the user base, principally through national geological surveys, civil engineers and utility operators. Stage 1 is also seeing the formulation of the overall strategy and analysis of the various supply, demand and system requirements. With the initial focus on urban subsidence, 186 European towns representing 26% of the total population have been identified for PSInSAR processing. Only 18 have so far been completed (including Sosnowiec and surrounding area in Poland), though Stage 2 of the project (2–5 years) is anticipated as funding the remaining processing are available. Among the 168 remaining urban agglomerations there are 14 Polish cities: Białystok, Bydgoszcz, Częstochowa, Gdańsk, Gdynia, Katowice, Kraków, Lublin, Łódź, Poznań, Radom, Szczecin, Warszawa and Wrocław. Subsequent stages will see the gradual inclusion of areas suffering risk from landslides, seismicity and flooding due to subsidence.

The Polish Geological Institute obtained PSInSAR processing results for the Sosnowiec area in mid-March 2004 (Fig. 5). Processing has covered 54 scenes of the ERS-1 and ERS-2 registered between 1992 and 2003. Actually, the study area extend from Tarnowskie Góry (NW), Dąbrowa Górnicza (NE), Jaworzno (SE) to Zabrze (SW). The city of Sosnowiec is located in the NW quart of the study area.

Sosnowiec is one of the largest and most important industrial centers in the Voivodeship of Silesia, located at the confluence of Czarna Przemsza and Biała Przemsza rivers in the Silesian Highlands, in the south east of the Upper Silesian Coal Basin. The development of Sosnowiec was possible largely due to its favourable geographical location and abundant natural resources. The mining of minerals in this area began at the turn of the nineteenth century. It was then the first hard coal mines were established. Recently, the “Sosnowiec” coal mine was closed in 1997 after 20 years of exploitation. Also other coal mines in the vicinity of Sosnowiec were closed, too.

Presently, the results of PSInSAR are subject of interpretation by the geologists of the PGI Upper Silesian Branch in Sosnowiec and in the future by the specialists from the AGH University of Science and Technology in Kraków. However, it is already possible to make preliminary remarks on these data:

❑ The indicated subsidence values between 1992 and 2003 vary between 10 mm and +10 mm. These values seems improbable, because much greater changes (up to metres) were indicated by other geodetic measurements. These values shows rather the tendencies of the slow ground motion with a very high accuracy.

❑ There is a distinct difference between the northern (relatively stable) and southern (unstable) area. This is probably related to the mining activity in the Upper Silesia. Mining activity in the northern area, including Sosnowiec city, practically ceased. In the southern area, the coal is still being mined.

❑ There are clearly visible linear anomalies oriented WNW–ESE formed by changing values of the ground motions. These linear anomalies correspond to structural features (faults, geological boundaries, etc.) which are parallel to the productive Carboniferous sediments forming the coal basin. Therefore, the linear anomalies could be interpreted as the surface expression of the active faults and other tectonic features. Further studies are necessary to explain this interesting phenomenon.

❑ There are many punctual negative anomalies indicating subsidence, mainly in the southern part of the scene. They should be subject of further, detailed studies and correlation.

The Sosnowiec case study and examples from other 17 European cities have indicated, that the geological application of PSInSAR are evidentis useful for monitoring subsidence in relation to mining and tunnelling, climate change-driven shrink-swell ground conditions, landslides, volcanic and tectonic motions, and for assessing localised flood risk.

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