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# THE USE OF SAR INTERFEROMETRY FOR THE STUDY OF LANDSLIPS IN THE POLISH FLYSCH CARPATHIANS

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**ABSTRACT**
The article discusses techniques for interpreting satellite images, which are capable of detecting and monitoring landslip zones, and presents a research plan for the study of landslips with the use of satellite interferometry. The exceptionally long-lasting and heavy rainfall that occurred in 1997 initiated more than 20,000 landslips within the Polish Carpathians. These landslips continue to pose a threat. Some of them move almost imperceptibly – slowly but continually – yet long-lasting periods of heavy rainfall can lead to catastrophe. The price can be human lives, as well as losses into the millions connected with the devastation of technical infrastructures and entire housing estates. The sheer number of landslips that occur in the Polish Carpathians makes the traditional ways of researching them insufficient. Satellite remote sensing allows capturing a large area of interest on a single photo. Many various satellites photograph the surface of the Earth using different techniques, allowing for the selection of the best-suited image type for a given application. Synthetic Aperture Radar (SAR) images are utilized in landslip studies. The images may be interpreted using the InSAR and/or PSInSAR techniques. Both methods are capable of detecting landslip zones and monitoring them in order to assess the risk of a sudden landslide. Information of this type is significant to local authorities when planning the activities necessary to protect the safety of inhabitants and the local technical infrastructure.

**KEYWORDS:** satellite remote sensing, InSAR, landslips

## INTRODUCTION

A landslide is a sudden movement of a mass of a surface bed of detrital minerals (eluvium) and underlying rocks caused by some natural forces or by some human activity ("Geological Nomenclature", 1959). This type of mass movement consists of a mass of rocks and/or eluvium sliding along some surface. The movement is driven by the Earth's gravity. Landslides occur particularly frequently on areas with favourable geological structure, i.e. when some permeable rock layers are intercalated by layers of impermeable rocks.

Landslides may have various causes. Most often the equilibrium of geological formations is disturbed by erosion and weathering phenomena. However, a sudden landslide may also be brought about by an earthquake or by soaking rainfall water (or water from a melting snow cap) in amounts large enough to overload the slope. Human activity may also result in unfavourable changes introduced to the geological environment, which in turn may result in landslides. Hydrological constructional works are mainly responsible for that, but earthworks on foundations of housing constructions or earthworks accompanying the construction of roads may also contribute, if some slope gets undercut or excessively loaded during the works.

Naturally originating landslides in Poland are most frequent in the Carpathian flysch, where the geological structure is most favourable – permeable sandstone layers alternating with layers of impermeable shales. Some Carpathian slopes have a history of mass movement in the later periods of the Quaternary age and are currently regarded as inactive. However, the slopes may re-activate in unfavourable external conditions, even if they do not exhibit any traces of past displacements. Landslide forms most frequently encountered in the Polish Carpathians are eluvium slippages and landslips. The forms develop mainly within cover soils. Most frequently in such cases the coluvium is not thicker than a few meters. Large structural landslides of areas of several acres have also been noted in the region. These pose the largest threat to hydro constructions, roads and residential areas since they may have a catastrophic character.

It is statistically proven that landslides mostly develop in the spring when snow melt. However, torrential rains may be another cause, proven already many times in the past. According to the Polish

Geological Institute, exceptionally long-lasting and heavy rainfall that occurred in 1997 initiated more than 20,000 landslips in the Polish Carpathians. A large fraction of all housing estates in that region have been built at the foot of a hill or on some slope. Therefore, the identification of possible landslide areas is very important to enable local authorities to appropriately plan the activities necessary to guarantee the safety of inhabitants and to protect the local technical infrastructure.

## LANDSLIP MONITORING METHODS

At the average density of one landslip zone per one square kilometre (Poprawa and Rączkowski, 2003; Rączkowski, 2003), the total number of landslips in the Polish Carpathians is too high in order for them to be monitored traditionally. Geology departments more and more often employ geophysical methods to obtain a global picture of changes taking place within studied landslip areas, in particular stress distribution and soil disintegration. The methods include, for example, electro-resistive tomography, electromagnetics and georadars. More recently, satellite images have also been used, which cover relatively large areas. For the purpose of landslip monitoring, Synthetic Aperture Radar (SAR) images taken by ERS1 and ERS2 satellites operated by the European Space Agency are particularly useful. The ERS-satellite-installed radars utilize microwave radiation in the wavelength range $\lambda$=3 cm (X band), $\lambda$=5 cm (C band) and $\lambda$=25 cm (L band). The images may be interpreted using InSAR and PSInSAR methods.

The Interferometric Synthetic Aperture Radar technique (InSAR) relies on measuring phase differences between two SAR images (radarograms). The measured differences may be computed into a single interferometric image, i.e. an interferogram (Perski, 1999; Góral and Szewczyk, 2004). ERS-1 and ERS-2 satellites have been used to produce raw radarograms. Besides the phase difference, intensity of the radar beam reflected from the Earth and reaching the receiver is measured to calculate the degree to which the waves are absorbed by the reflecting surface. A phase difference of 360$^o$ corresponds to one half of the wavelength of the used radiation. For ERS-1/ERS-2 satellites, this wavelength amounts to 5.6 cm. An interference image computed from two radarograms of the same terrain taken at different times allows detecting changes in elevation of the terrain. Since the satellite-Earth line is not ideally perpendicular to the Earth's surface, beam angle correction must be taken into account. It turns out that a 360$^o$ phase difference in an interferogram corresponds to 2.58 cm rather than to a 2.8 cm change in terrain elevation.

Images taken at various orbits have different viewing geometries and may be used to produce stereoscopy effects, i.e. for elevation mapping. The InSAR technique relies on the very high sensitivity of the radar signal phase to the transceiver-target distance. If two images of the same terrain are simultaneously taken from two close orbits (separated by several tens or hundreds of meters), phase differences may be effectively measured individually for each pixel of the image. These differences may be then computed into elevations of individual pixels, in effect producing the so-called Digital Elevation Model (DEM), i.e. a 3D map of the terrain. On the other hand, if two images of the same terrain are taken from the same orbit but at different times, terrain deformations on the order of a fraction of one centimeter may be detected. This technique is known as Differential SAR Interferometry (DInSAR). In practice InSAR and DInSAR acronyms are treated as synonyms.

The Permanent Scatterer Interferometry (PSInSAR) technique developed at the University of Technology in Milan, Italy, facilitates the detection of distinctive objects (called here Permanent Scatterers or PS) and minimizes the adverse influence of weather conditions by using more than 30 images of the monitored area (Hanssen, 2004). The PS points usually correspond to such artificial objects like buildings, transportation infrastructure or industrial facilities, but may also correspond to some natural elements of the terrain, e.g. geological outcrops. One of the unquestionable advantages of the PSInSAR technique is its capability to measure displacements to the accuracy of a few millimeters. On the other hand such high accuracy is also a limitation of the method since fast deformations of the monitored terrain (rate of change above 5-6 cm per year) will remain undetected. Another limitation of the method is that it requires at least 3 PS points per square kilometre, which means that the method practically works only in highly urbanized areas. Researchers working at the University of Technology in Bari, Italy, have partly solved the latter problem: the refined SAR data processing algorithm (called Stable Point Interferometry over Unurbanized Areas, SPINUA) allows applying the PS technique to non-urbanized areas (Bovenga et al., 2004). The PSInSAR method processes so many satellite images that it may be effectively put to work only in scientific centers having at their disposal relatively large processing powers – for many centers it is yet another practical limitation of the method.

Landslips often move so slowly (a few millimeters per year) that inexperienced observers notice nothing. However, even if almost imperceptible, the movement is steady. During such periods landslips cause no damage. But torrential rains or long-lasting rainfall periods may activate the slips and transform them into sudden landslides of masses of eluvium. The above mentioned methods of satellite image interpretation allow detecting millimeter terrain deformations, and therefore are ideal tools to assess landslide risk on monitored areas.

Research on the usefulness of satellite remote sensing technique for the detection and monitoring of

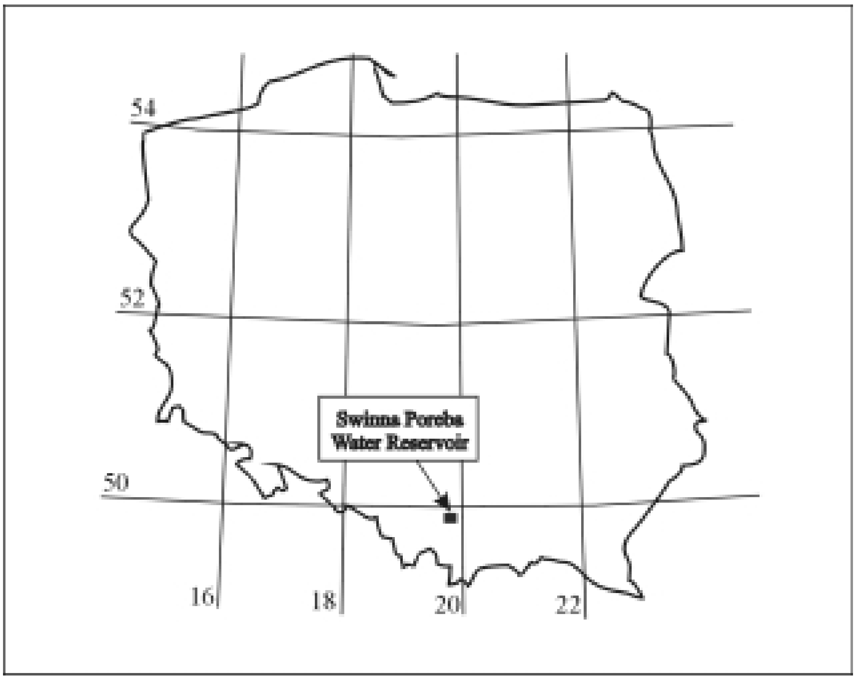


**Fig. 1** Location of research area.

landslip zones is conducted in all countries affected by landslides. The most intense works have been done in Italy (e.g. Blonda et al., 1999; Arturi et al., 2003) and France (e.g. Fruneau et al., 1996; Delacourt et al., 2003). Landslip zones monitored in Italy by means of satellite interferometry include Salerno near Naples (Arturi et al., 2003), where a catastrophic landslide occurred in 1998. This terrain is constantly endangered by landslides. Additionally, during intense rainfalls the areas surrounding Vesuvius are endangered by sudden and very fast mud-flows due to an accumulation of pyroclastic formations. A comparative study of geodetic terrestrial surveys vs. satellite interferometry surveys conducted in this region indicated a high potential of the latter method if applied to monitor endangered areas. Unfortunately, due to its present technical limitations, the method may not yet be applied to routinely generate early warnings about upcoming threats. The monitoring of a landslip zone in La Clapière near Nice in France by means of the satellite interferometry method allowed detecting and identifying boundaries between individual blocks of which the slipping mass is composed (Fruneau et al., 1996). This information is extremely important since each block may behave differently, giving rise to local instabilities within the landslip zone. Information gained from the processing of satellite images may be used, for example, to better plan a terrestrial geodetic network.

**RESEARCH PROPOSAL FOR THE STUDY OF LANDSLIPS IN THE CARPATHIAN FLYSCH**

Due to a large number of landslips that occur in the Polish Flysch Carpathians and the necessity to monitor them, a feasibility study on satellite interferometry monitoring has been proposed. The corresponding research proposal has been approved and will be carried out under the European Space Agency patronage.

The main objectives of the proposal (apart from checking the feasibility of applying the satellite interferometry to monitor landslips in the Polish Flysch Carpathians) include:

- to identify landslip zones and block boundaries within each zone
- to monitor individual blocks in order to detect local instabilities within the slipping masses
- to record the time evolution of landslips
- to verify if some parameters (image features) useful for quick detection of landslip zones exist.

The research will be carried out on terrains surrounding the Świnna Poręba locality in Mucharz county, close to the Wadowice-Sucha Beskidzka road (Fig. 1). The „Świnna Poręba” impoundment lake under construction since 1986 (the works are scheduled to be completed by 2010) is localized on the Skawa river at the foot of the Jaroszowicka Góra, Kurczyna, Upaliska and Starowidz hills. Till 1998,

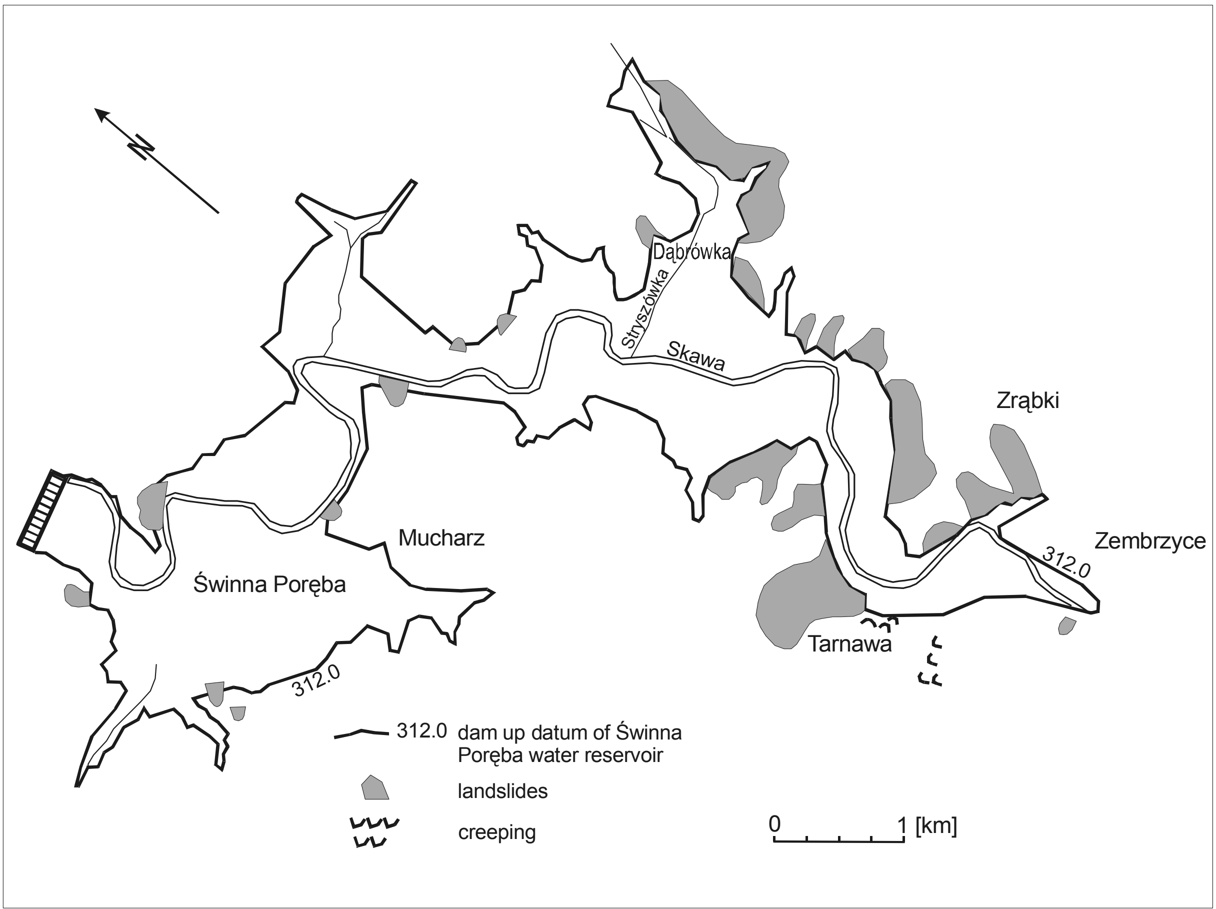


**Fig. 2** Distribution of landslides around the Świnna Poręba water reservoir (after Fischer, 1998).

more than 20 landslip zones have been identified on the surrounding hills (Fig. 2). The landslips are localized in the area where the Magura beds are thrust over the Silesian Nappe (Fischer, 1998). However, the landslip-prone area is larger than the forecasts. Two dilatation caves and some slope cleft rifts have been detected at the Kurczyna hill, located close to the construction site (Gałaś, 2001). The hill is part of the Silesian succession considered to be less prone to landslips than the Magura beds. Nevertheless, numerous landslips have already been detected within the Silesian succession in front of the Magura Nappe. Subsequent landslips may activate under the influence of variable water levels in the constructed lake. There is also a concern that due to tree stumping and soaking up the water, the currently inactive or stabilized landslips may activate. The impoundment lake itself may be endangered by landslips, its volume being reduced by sediments from the slipped masses. Should a large rock volume suddenly slide into the lake, the water may overflow the dam and flood the areas downstream.

Since terrain conditions continually vary due to works being carried out on the impoundment lake construction, the Świnna Poręba area is particularly attractive for the testing capabilities of the satellite interferometry as applied to monitoring landslips within the Carpathian region. Five pairs of images taken between 2001 and 2005 have been selected for interpretation. Images taken during the winter season were avoided since snow cover may influence elevation readings. Besides the interpretation of the selected satellite images, geophysical terrestrial surveys in some selected areas are also proposed as a part of the proposal.

## SUMMARY

The threat posed by landslips occurring in the Polish Carpathians is high and various remedies restricting the associated risks should be looked for. One of the approaches is to monitor the landslip to precisely detect its zone and to study its dynamics. Access to archive satellite images collected by the European Space Agency enables analysing the history of some known landslip zones, which may lead to the discovery of image features useful as indicators of the "susceptibility" of the given area to landslips. Such indicators may in turn allow alerting local authorities that some actions are required to protect inhabitants and endangered technical infrastructure.

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