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SATELLITE REMOTE SENSING FOR WATER EROSION ASSESSMENT

MONITOROWANIE EROZJI WODNEJ GLEB Z WYKORZYSTANIEM TELEDETEKCJI SATELITARNEJ

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Introduction

Soil erosion is a natural process that detaches and transports soil material through the action of an erosive agent (Lal, 2001). At a global scale, among erosive agents like wind, gravity and anthropogenic perturbations, the water agent has the biggest impact on land degradation. This generates serious economic problems due to soil depletion, reduced crops and decreased water quality. In order to prevent this process some steps concerning erosion and the estimation of erosion factors must be taken. Detection of erosion features and eroded areas, as well as assessment of factors controlling erosion are very complex tasks which can be solved thorough the integration of spatial data, topographic maps, field measurements and surveys, aerial photographs and satellite imagery. The most promising method of data collection is remote sensing, due to its potential to acquire homogeneous data over large areas with a regular revisit capability. Constantly developing remote sensing technologies, satellite missions providing high-resolution data, and new methodologies open wide possibilities in water erosion assessment and should enable the application of soil and water conservation strategies at different spatial scales and organization levels.

The European Union obligates its member states to undertake appropriate steps to prevent soil degradation. Numerous EU directives and Polish ecology policy put special emphasis on the need to control water erosion processes through identifying the eroded areas and assessing the erosion factors. The importance of remotely sensed data in this process is clearly indicated. Moreover, the EU countries within the Framework-7 Programme are encouraged to research the influence of water erosion on soil degradation.

Basically, there are three different approaches for soil erosion assessment. The first one is through field measurements of soil erosion rates. These measurements are used forspecific erosion factor assessment, model development or validation purposes, but not directly for spatial evaluation of erosion (Vrieling, 2005). The second approach is erosion field survey, in which erosion features are identified and assessed in a qualitative or quantitative (via repeatable measurements) manner. However, these surveys only allow spatial mapping of erosion features which is limited to small areas like small catchments. For larger areas this method becomes difficult. Moreover, field surveys are generally expensive and time consuming.

The third method is a quantitative procedure for the estimation of soil loss through the integration of spatial data on erosion factors. Several models concerning these factors exist, of which the USLE (Universal Soil Loss Equation) is the most frequently used. Such models require large amounts of detailed data on a wide variety of rainfall, soil, vegetation and slope parameters (Vrieling, 2005). Selection of the model and required factors is region-specific, dependant on the characteristics of the area of interest and erosion processes that occur.

New possibilities for water erosion assessment are offered by remote sensing methods, especially SAR interferometry using data from new, high resolution sensors. The main objective of this study is to present existing and potential methods for water erosion and erosion factors assessment, putting the emphasis on the utility of radar images (SAR) in erosion studies. In addition, the possible use of new high-resolution radar images acquired onboard the TerraSAR-X satellite is described. Finally, ongoing research on water soil erosion in the area of the Trzebnickie Hills using TerraSAR-X images and radar interferometry is presented.

Methods of water erosion assessment using remotely sensed data

All the spatial data which can be used in erosion mapping, mapping method validation, qualitative and quantitative erosion assessment can be obtained from existing topographic, soil, land use maps, field measurements, weather reports, terrestrial and airborne laser scanning, aerial photographs and satellite imagery. Among these possibilities, remotely sensed data, basically satellite imagery, provides repeatable measurements over large areas with desirable spatial and temporal resolution. Additionally, variables obtained from such images can be supported with other spatial data, such as laser scanning, to extract new or more accurate information (Lubczynski, Gurwin, 2005). With satellite imagery it is possible to detect eroded areas and determine their spatial range, as well as assess erosion factors like vegetation cover, slope, or soil type. These parameters can then be used as input factors in erosion models.

Optical satellite systems have been most frequently applied in erosion research (Vrieling, 2005). These sensors operate in the visible, near infrared, shortwave infrared and thermal infrared parts of the electromagnetic spectrum. Spatial resolution of the images obtained with optical sensors varies, depending on the satellite platform, from 120 m (Landsat TM thermal band) and 90 m (Aster TIR) to a meter-resolution IKONOS (4.0 m) or QuickBird (2.44 m). Nevertheless there are some obstacles for the wide use of such data. Particularly, optical waves back-scattered from the terrain and registered by the sensor are sensitive to weather conditions (dense clouds, rain, etc.) and, as these are passive sensors, images can be obtained only in daylight. To overcome these problems, radar images from satellites like ERS-1 and 2, JERS-1, RADARSAT-1, ENVISAT or the new high-resolution TerraSAR-X can be used for erosion research. The main advantages of radar systems are weather independence and both day/night acquisition possibility (as for other active sensors).

Satellite data can be applied to directly detect erosion or erosion consequences. The individual identification of eroded areas and large erosion features is possible through visual satellite image interpretation, band composites analysis or image composites from different sensors. Delineation of eroded areas on multi-temporal data gives the possibility to evaluate its increase/decrease (Fadul et al., 1999). An alternative method for visual image interpretation is the extraction of eroded lands using classification methods. Several studies concerning the application of different methods have been conducted (Serveney, Prat, 2003; Floras, Sgouras, 1999). Research has proved that high resolution data performed better in classification, as well as the larger number of spectral bands used in classification step.

Change of surface states can supply direct information on erosion occurrence (Vrieling, 2005). Using amplitude and phase information carried by two radar images, having approximately the same geometry and acquired within a certain time span, it is possible to apply the repeat-pass interferometry technique. This method allows delineation of slight (sub-cm) land deformations and can be used for DEM (Digital Elevation Model) generation. A more promising product derived from SAR imagery is the coherence map. When the characteristics of the soil material on both acquired radar images are very similar, the coherence is high. Changes in the top soil layer caused by erosion can cause significant temporal de-correlation. Nevertheless, the de-correlation can be caused by other factors such as differences in satellite paths for acquired images, vegetation, soil moisture and roughness (Wegmuller et al., 2000; Baghdadi et al., 2002). The topographic de-correlation influence due to the local terrain slope can be separated from the overall de-correlation between two radar images using the ratio coherence imagery method of (Lee, Liu, 2001). This method can effectively expose the de-correlation component due to erosion in coherence maps. However, for the correct interpretation of coherence imagery, integration with other spatial data, such as optical imagery is needed.

Remote sensing techniques can be also applied for assessing erosion controlling factors. The most important are topography, soil properties, vegetation cover and tillage. These factors are of the biggest importance in evaluating erodibility, which is the measure of soil resistance to the erosion process.

The information concerning topography can be derived from topographic maps. Nevertheless, most of the erosion models require a Digital Elevation Model of the study area. To obtain DEMs, several methods using remotely sensed data are available. With stereo optical satellitel imagery (SPOT, ASTER), a DEM of an accuracy of < 20 m can be reached (Toutin, Cheng, 2003). Interferometric SAR processing of the radar images obtained during SRTM (Shuttle Radar Topography Mission) provided elevation data with a resolution of 30 m. Moreover, a DEM derived as one of the intermediate products in interferometric processing of SAR data (ERS, ENVISAT or TerraSAR-X) can be used in erosion studies. DEMs are the source of the slope parameter which is needed in all of the water erosion models. Additionally, the information about the area and slope length can be obtained.

Basic soil properties which can be determined using satellite images are soil moisture, roughness, texture and organic matter content. All of these can be derived through the visual interpretation of optical images and soil pattern delineation, as well as through the image classification process. However, soil property evaluation using optical satellite images can be difficult because the topsoil reflectance of the Earth's surface is influenced by many factors in parallel. This factor variety in some cases allows evaluation of surface states, instead of distinct soil property determination. These surface states can be than related to erosion potential using field measurements (Vrieling, 2005). Additionally, the reflectance by vegetation in some areas makes soil mapping through satellite imagery impossible. Several methods exist to separate soil and vegetation signal from overall reflectance. Knowledge of the regional soil types and their respective climax and degradation forms in combination with their spectral characteristics, enables these methods to be applied in erosion assessment (Hill et al., 1995). SAR imagery is very sensitive to soil properties, especially soil roughness and moisture. The potential use of radar data in soil property assessment depends on the radar and individual image parameters (wavelength, polarization, incidence angle). Several authors have claimed success in surface roughness evaluation to determine the possible run-off and soil erosion (Baghdadi et al., 2002).

Vegetation cover, basically plants' roots attach and bind soil particles, protects soil from erosion. Depending on the type, plants have different abilities to protect topsoil against run-off. In erosion studies, land cover classification is usually performed with optical satellite image composites.

Several approaches to classification exist, for example supervised, unsupervised or hybrid (combined supervised and unsupervised classification) methods. Moreover, neural networks are frequently used for satellite images classification. The visual interpretation of such classified images requires additional ground-truth data. Accuracy of vegetation cover determination depends mainly on the satellite imagery used for classification and sensor properties. Multi-band approaches, combining images from different sensors, might be useful for increased classification accuracy. Due to the temporal changes in land cover over a year, multi-temporal imagery can also considerably increase classification accuracy. The other method for vegetation assessment is through the vegetation indices. Indices are ratios between specific image bands which can stress particular vegetation properties and can be used for quantitative and qualitative vegetation evaluation. For example the well known NDVI (Normalized Difference Vegetation Index), defined as near infrared (NIR) minus red band divided by the sum of the two is very useful for discrimination between vegetated and bare soils. Nevertheless, all of the optical sensors are sensitive to the weather conditions and cloud coverage. To overcome these obstacles, radar images can be used. Through the classification of multi-temporal and multi-polarized SAR images, combined with images acquired by different sensors and with different incidence angles, it may be possible to monitor vegetation cover and its condition.

The other erosion controlling factors are tillage and land conservation practices. Because tillage changes soil roughness, visual or automated satellite image classification should enable to discriminate the areas where different tillage methods were applied. Authors of several studies have used optical satellite images to assess soil conservation and tillage practices. However, SAR images, because of the sensitivity to soil roughness, performed better for this purpose (Leek, Solberg, 1995). In general the rougher the soil surface, the greater backscatter registered by radar. Backscatter is also influenced by the tillage row direction. Although SAR images can be used successfully for aluating evtillage practice, several barriers exist – for example existing dense vegetation cover. This can be overcome by the integration of SAR images with optical images, as well as the multi-temporal approach.

Remotely sensed parameters for erosion models

Data concerning erosion factors discussed above can be integrated and used in water erosion modeling. A large number of erosion models exist. Through these models quantitative evaluation of soil loss can be obtained. Additionally, the influence of erosion on the environment can be assessed and the process expansion can be predicted. This can lead to the development of change scenarios for eroded areas, in order to prevent subsequent soil degradation.

Water erosion modeling requires various input data. Some of these spatial data can be obtained using remote sensing techniques. Due to the constantly increasing resolution of satellite imagery, providing accurate data over large areas, remote sensing is a very strong tool in erosion modeling.

One of the most widely used models is USLE (Universal Soil Loss Equation) and its modified version RUSLE (Revised Universal Soil Loss Equation).

$$A=R*K*LS*C*P$$

Where:
A – estimated average soil loss in tons per acre per year
R – rainfall-runoff erosivity factor
K – soil erodibility factor
L – slope length factor
S – slope steepness factor
C – cover-management factor
P – support practice factor

Remotely sensed data can contribute to the assessment of almost all these factors. The soil erodibility factor K is the measure of soil resistance to erosion; it strongly depends on the soil particle size, soil roughness and organic matter content. Many soil properties, as mentioned previously can be successfully mapped using satellite images visual interpretation or image classification. Slope length factor L and slope steepness factor S represent the effect of slope length and slope steepness on erosion respectively. These factors can be best determined using DEMs, obtained for example using interferometric SAR image processing to provide high-resolution digital information about elevation over large areas. The cover-management factor reflects the effect of cropping and tillage on erosion rates. It consists of a few subfactors: surface cover, canopy, soil roughness, moisture and land use. As was mentioned previously, most of these factors can be obtained from satellite optical and radar images. The last factor from the USLE/RUSLE model which can be supported with remotely sensed data is the P factor, reflecting the impact of support practices on erosion rates. It takes into account the tillage method (for instance strip cropping, straight row farming, up-and-down slope tillage). As shown by several studies (Major et al., 1993) sensitivity of radar to soil surface roughness can provide information about tillage practices.

Potential of high-resolution TerraSAR-X images in erosion studies

TerraSAR-X is an active microwave system providing high-resolution radar images. Its main advantages are image acquisition day and night and in all weather conditions; big spatial coverage; short revisit time; and soil surface conditions sensitivity. The first aim for which TerraSAR-X images can be used in erosion studies is the determination of eroded areas through interferometric SAR processing. This technique is used for measuring the relative height (DEM) and height changes. It should be also applicable for small surface change detection due to water erosion processes. As mentioned previously, one of the radar image processing products is a coherence map which shows backscatter de-correlation between two image acquisitions. Water erosion influences on the topsoil can cause image de-correlation and the low coherence areas can indicate surface changes due to water soil erosion. TerraSAR-X images can be used in determination of eroded areas for high-resolution and weather independence, as well as short revisit time which can be an advantage for regions where erosion processes are very intensive. Moreover, the high-resolution imagery might be less sensitive to volume scattering. As mentioned before, TerraSAR-X images can also assist in obtaining input spatial data for erosion models by providing high-resolution DEMs, land use and vegetation coverage maps, soil properties evaluation, crop determination and tillage method identification. The interpretation of radar images can be performed through visual or automated classification. Several classification methods, such as contour tracing, have been already applied in TerraSAR-X image processing. One of the advantage of TerraSAR-X is the capability to adapt image parameters to local conditions. For instance, HH polarization can perform better in the evaluation of soil properties and identification of direct erosion features, whereas VV polarization might be better for vegetation cover evaluation; the local incidence angle plays an important role for defining the roughness and moisture of the soil (Baghdadi et al., 2002). In most cases, for full utilization of TerraSAR-X images in erosion studies, multi-temporal and multi-polarization data are required.

Research area Trzebnickie Hills

The application of TerraSAR-X images in erosion assessment is currently under development within the DLR (German Aerospace Agency) project (LAN0514) running at the Institute of Geodesy and Geoinformatics at Wroclaw University of Environmental and Life Sciences. The area under study is the region of the Trzebnickie Hills located in western Poland, where the effect of water soil erosion has a big impact on the soil properties and quality. The sensitivity of the loess soils in this region to erosion and the high probability of water erosion can cause soil degradtation. Figure 1 shows the erosion features, in the form of rills and gullies, observed in the area of interest.

In our research we assume that the Interferometric processing of TerraSAR-X Spotlight images, with resolution of app.1m, can provide valuable information on local surface changes caused by erosion processes. Coherence of images should be secured by one repeat cycle temporal baseline (11 days). As the thickness of loess layer is more than 2–3 m, correlation between image acquisitions should be good (homogenous material should give similar backscatter). In the case of big changes due to erosion processes, or for images with a longer temporal baseline, it should be possible to delineate eroded areas through the coherence maps. Within the project it has been planned to acquire 20 images with temporal resolution of 11 days, HH polarization, due to its lower sensitivity to backscatter from vegetation cover, and an incidence angle of app.23° to decrease image sensitivity to soil roughness. First radar images (Fig. 2) obtained through the DLR project were processed with partial success due to some problems with the implementation of the algorithm for interferometric processing of the high resolution SpotLight mode, in which images were acquired. Nevertheless, some preliminary conclusions can be drawn. The first interferogram (Fig. 2) generally shows very good coherence. Although it’s still difficult to interpret interferometric fringes, we can observe some buggy fringes at the edges of the interferogram which are the result of the varying Doppler frequency due to the antenna motion, as well as improper processing due to the algorithm applied. Moreover, we can observe some areas with substantial decrease of coherence. This might be caused by the erosion process or by other factors, particularly soil properties. In both cases more detail research will be performed in subsequent studies.

The next research will focus on the determination of the extent of the areas affected by erosion, temporal variability of the erosion affected areas and the estimation of terrain elevation changes caused by erosion. Moreover the utility of TerraSAR-X images in erosion modeling will be studied.

Conclusions

This article exposes the problem of water soil erosion raised in many EU directives and Polish Ecology Policy as one of the main cause of land degradation. The study presents an overview of erosion assessment methods and points out the areas in erosion researches where satellite images can be used. In particular, it focuses on the possibility of obtaining input parameters for erosion models using satellite imagery and describes the possible application of TerraSAR-X images in erosion studies. The ongoing research on the utility of high-resolution radar images is briefly described. Although we were not able apply interferometric processing for Spotlight images correctly, the first rough results look sufficiently promising to justify further investigation. This innovative application of TerraSAR-X images, will make a contribution not only to erosion research, but also show the potential of TerraSAR-X Spotlight images and influence the development of TerraSAR-X Spotlight image interferometric processing. It will also enable steps to be taken towards preventing soil degradation in the area of The Trzebnickie Hills; the results obtained will be verified against existing measurements developed by soil scientists.

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Streszczenie

Erozja wodna jest jednym z głównych czynników powodujących degradację gleb. Istnieje wiele metod oceny tego zjawiska w sensie ilościowym i jakościowym. Większość z nich wykorzystuje zintegrowane dane przestrzenne, w szczególności dane dotyczące czynników wywołujących erozję. Mogą być one pozyskiwane z różnych źródeł, między innymi z: istniejących map glebowych, użytkowania terenu i topograficznych, stacji meteorologicznych, pomiarów terenowych, zdjęć lotniczych i obrazów satelitarnych. Przewagą technik zdalnych jest głównie możliwość pozyskiwania w krótkich odstępach czasowych jednorodnych danych obejmujących duże obszary. Wybór odpowiednich metod i typu danych teledetekcyjnych możliwych do wykorzystania do badania procesów erozyjnych jest podyktowany głównie rodzajem danych wynikowych, które chcemy uzyskać. Jednymi z podstawowych kryteriów wyboru są parametry sensorów, takie jak długość fali, rozdzielczość przestrzenna i czasowa, czy też, w przypadku danych radarowych, polaryzacja. W pracy przedstawiono krótki przegląd możliwości zastosowania technik zdalnych w badaniach erozji wodnej oraz czynników wywołujących to zjawisko. Głównie skoncentrowano się na możliwościach wykrywania i oceny miejsc objętych zjawiskiem erozji oraz oceny czynników wywołujących erozję za pomocą obrazów radarowych SAR. Ponadto, podkreślono potencjał nowych wysoko rozdzielczych obrazów radarowych TerraSAR-X w badaniach erozyjnych. Przedstawiono również pierwsze wyniki realizowanego na obszarze Wzgórz Trzebnickich projektu (grant Niemieckiej Agencji Kosmicznej DLR LAN0154) dotyczącego monitorowania zmian ukształtowania powierzchni terenu spowodowanych erozją wodną, Pokazano pierwszy interferogram uzyskany z danych TerraSAR-X w trybie spotlight. Wskazano problemy związane z opracowaniem tego typu danych.

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Figure 1. The appearance of large erosion features in the form of rills and gullies at agricultural fields in the area of Trzebnickie Hills

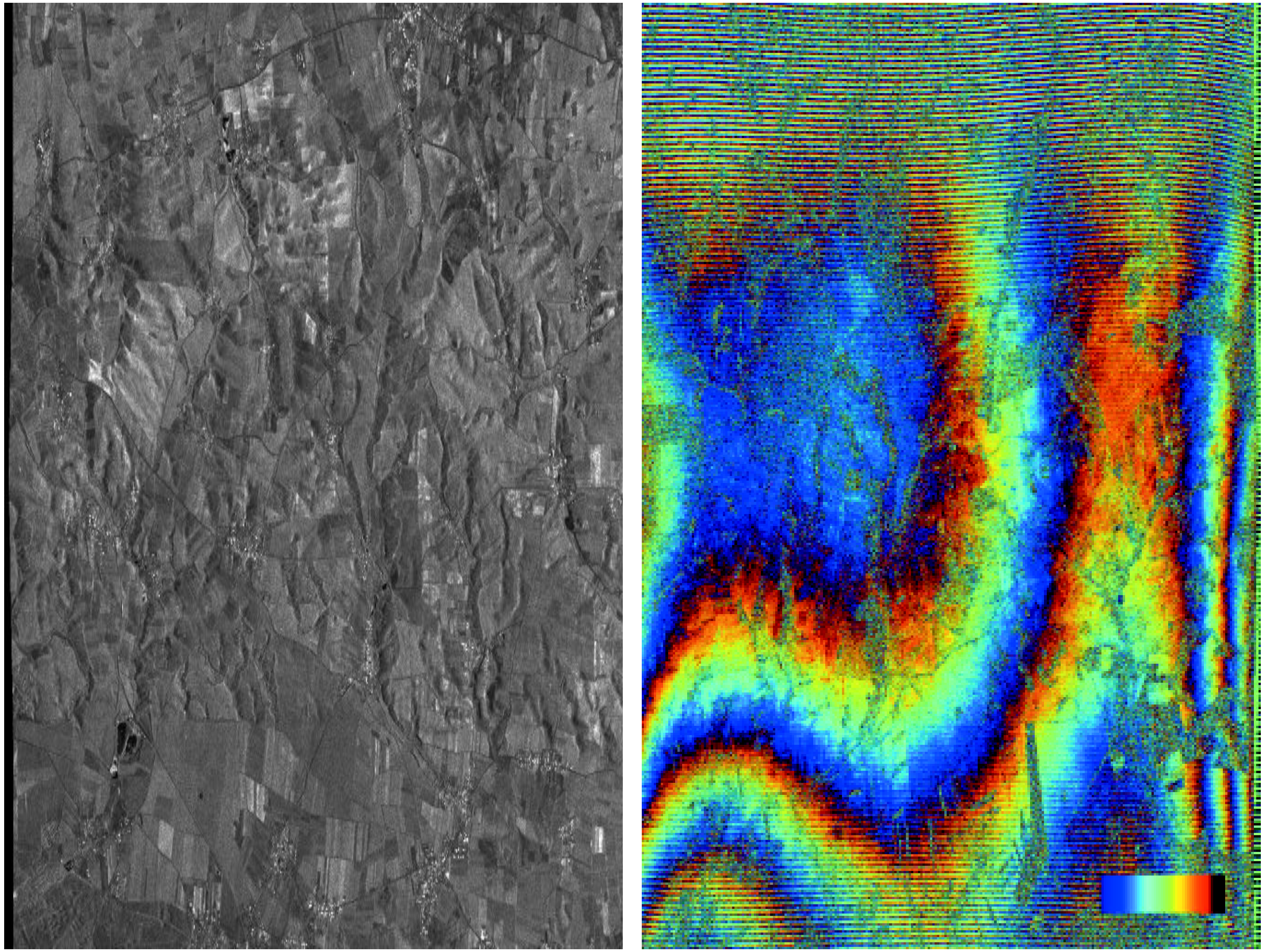

Figure 2. a – TerraSAR-X Spotlight image, the area of Trzebnickie Hills: b – the first interferogram processed with DORIS processor (Kampes et al., 2003)