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Identification of Severely Eroded Soils from Remote Sensing Data Tested in Rišňovce, Slovakia

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ABSTRACT

The abrupt development of remote sensing and GIS mainly in 1990s brought new opportunities to develop improved tools for erosion assessment and advanced methods for mapping of eroded soils. This paper provides methodological achievements enabling the identification of erosion from remote sensing data reached in Slovakia.

The erosion patterns occurring at test site in Rišňovce area were detected from aerial photographs and SPOT PAN image, using three different approaches. Computer-aided visual interpretation of aerial photographs was based on vectorization of erosion patterns on the computer screen, using the scanned and georeferenced aerial photographs mounted to a photomosaic. The satellite image was interpreted firstly by computer-aided visual interpretation similarly as for aerial photographs, and later by image classification.

The result shows, that the eroded soils can be successfully mapped from both the aerial photographs and the satellite images. The accuracy of resulting maps is much better than the accuracy of maps based on field survey. Since these methods were successfully tested, the erosion mapping based on visual interpretation of aerial photographs and satellite images became routinely used in Slovakia. Since now first hotspot agricultural areas (Levice District and Trnavská Hilly Land) were mapped at a scale of 1:50000.

INTRODUCTION

Slovakia is a mountainous country with limited acreage of agricultural land (0.46 ha per capita, Statistical Office of the Slovak Republic, 1996). Soil erosion damaged a large portion of agricultural land; approximately 12% is severely damaged and 43% is partially damaged (Fulajtár and Janský, 2001).

The geographical distribution of eroded soils is one of the most important information required for soil conservation. Despite of that these data are very limited. Spatial patterns of eroded soils are too complex, and conventional mapping based on field survey, which was used earlier, did not provide satisfactory results. The erosion maps resulting from field survey are, at best, only rough estimates of real erosion distribution.

New possibilities for developing detailed maps of eroded soils were introduced by remote sensing. The possibility to use the aerial photographs for soil mapping has been known for a long time (Goosen, 1967). Commonly they were used to support conventional geomorphological methods (Strömquist, 1990), and also for direct identification of sheet, rill and gully erosion (Frazier et al., 1983, Strömquist et al., 1985). Aerial photographs from different time periods allow the study of erosion dynamics, mainly the growth of rills and gullies (Alam and Harris, 1987). In Slovakia the principles of erosion mapping from aerial photographs were provided by Juráni and Šurina (1973). The erosion assessment from aerial photographs was done mainly in subalpine areas damaged by tourism and grazing (Midriak and Petráš, 1972). The erosion distribution at agricultural land was studied by (Fulajtár, 1994).

Since 1970s the satellite images brought new opportunities. In some studies, for example in assessment of erosion distribution in Slovakia, they served only as complementary data supporting conventional methods (Fulajtár and Janský, 2001). Another studies use them as main source of information, but only for indirect detection of eroded soils. In this case the erosion pattern was not identified directly according to spectral reflectance of the land surface, but the images were used to separate the investigated area into land types based on geology and vegetation, and because it is presumed that the erosion distribution respects the geographical conditions, the obtained land types are interpreted as erosion regions. This approach was used by Folving (1993) in Mediterranean.

While the indirect erosion detection is popular mainly when large areas should be assessed, the direct detection can be used as well for detailed investigation of erosion distribution, as for assessment of large areas. The erosion patterns are identified directly using the differences of spectral reflectance of the land surface. This identification can be done either by visual interpretation of images or by image classification. The visual interpretation provided usually good results and despite of intensive development of numerical interpretation approaches, it is still popular. It is used mainly for erosion mapping of large areas in third world countries (Tripathi and Rao, 2001, Sajatha et al., 2000).

Numerical interpretation approaches are developing mainly in last two decades. Different spectral bands (visible, infrared, thermal, microwave) can be used for image classifications (Metternich and Zinck, 1998). One of first uncontrolled classifications of satellite image aimed to erosion detection was provided by Seubert et al. (1979). Better results were achieved by controlled image classification. Kolejka and Shallal (1997) testing two-step

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image classification (uncontrolled and controlled) demonstrated the advantages of controlled classification. However, the spectral reflectance of land surface is very complex and many studies showed, that image classification, unsupported by other data, do not express the erosion patterns with required accuracy. Bocco and Valenzula (1988) and Lundén et al. (1990) tried to overcome this problem by rectifying the image classification by visual interpretation. The combination of image classification and visual interpretation was recommended also by Lantieri et al. (1990) and Pilesjö (1992).

Apart of studies testing different approaches of erosion detection a lot of attention was paid also to analyzing the relations between basic soil characteristics and their spectral reflectance. Most remarkable is the correlation of spectral reflectance with soil organic matter (Dawis and Swain, 1983). Another correlating characteristics are the soil moisture, soil texture (especially the clay content) and mineralogical composition (Mulders, 1987, Irons et al., 1989). The correlation of soil color with the spectral reflectance in visible band was studied by Escadafal et al. (1989) and Escadafal (1993).

In Slovakia Šúri and Lehotský (1995) provided first uncontrolled image classification aimed to erosion detection and at the same time first controlled classification was published by Fulajtár (1995). This paper pursues the experiences gained from earlier studies done in Slovakia (Fulajtár, 1994, 1995, Šúri and Lehotský, 1995). It provides main methodological achievements reached by testing different approaches of erosion identification from aerial photographs and satellite images using computer-aided visual interpretation and image classification. In this way it should contribute to the development of methodology for erosion mapping.

MATERIAL AND METHODS

The detection of erosion patterns is possible thank to correlation of spectral reflectance to soil organic matter and to soil color reported by Dawis and Swain (1978) and Escadafal et al. (1989). As these relations are well developed in visible region of spectrum, the panchromatic aerial photographs and satellite image were used. The identification of erosion patterns is based on color difference between the topsoil and subsoil. If the soil is severely eroded, a significant part of dark A and B-horizon is removed and the C-horizon, which is usually lighter in color, is exposed. Yellowish C-horizons have considerably higher spectral reflectance than gray or brown A-horizons and brown or rusty B-horizons; therefore they form bright patterns easily detectable by remote sensing. This relationship is best expressed in soils having strong color contrast between the topsoil and the subsoil, as it was detected in loess hilly lands of Slovakia (Fulajtár, 1994b).

As these erosion patterns are well detectable in visible region of spectrum, the panchromatic black and white aerial photographs (second half of August, 1985, size of 23 cm by 23 cm, scale of approximately 1 : 29,000, 60% overlap within the strip and 20% between the strips) and panchromatic black and white SPOT PAN satellite image (mid-March, 1990) were used.

Processing the remote sensing data was done with the aid of EASI/PACE software. At first the erosion was detected from aerial photographs using the ***computer-aided visual interpretation*** based on ***vectorization*** of the erosion patterns on computer screen from the scanned and georeferenced photographs mounted into photomosaic. After that the interpretation of SPOT PAN image was done in two ways, firstly by ***visual interpretation*** similarly as for aerial photographs, and secondly by ***image classification***. The image classification involved the following steps:

Stratification of the study area was done according to crop cover. As the vegetation influences the spectral reflectance of the land, the study area was separated to strata according to crop cover. All further steps were done for each stratum representing different crop cover separately.

Uncontrolled image classification was based on the presumption, that the differences of spectral reflectance of the land caused by erosion can be detected by numerical procedures offered by the GIS software used. Since the erosion patterns are relatively homogenous in spectral reflectance, it may be expected, that there will be a link between the classes generated by uncontrolled classification and the erosion pattern. To find this link, it is needed that the initial number of classes generated by image classification should be higher that the final number of required erosion categories. Some of generated classes should be grouped, in order to obtain such a class, which would match the shape of erosion pattern. Next step should be the grouping of initial classes. Two ways of grouping were tested - the unsupervised aggregation and supervised aggregation.

Unsupervised aggregation was performed automatically by computer using specific software capabilities. The operator decides only the number of classes, which should result from the aggregation, and the GIS tool groups the classes generated by uncontrolled image classification according to mathematical rules. The software determines which classes should be grouped together, according to their mutual similarity reflected by the differences between mean values of each cluster.

Supervised aggregation groups the classes according to an expert judgment of the operator, who decides not only the required number of classes, but also which classes should be grouped together. The decision is based predominantly on visual assessment of the result obtained from uncontrolled image classification with regard to original non-classified image. If certain class represents the erosion pattern properly, its shape should coincide with the shape of bright pattern representing the eroded soils on original non-classified image. If this is not true, the examined class should be grouped with some other class.

The results obtained by all tested approaches were compared and verified. The verification was done in two ways. Firstly the visual assessment based on mutual comparison of used media and resulting erosion maps was done. Later the field verification based on augering was performed. The auger observations were arranged to transect and each point was located carefully using the conventional methods for location of points with respect to well identifiable orientation points and GPS for coordinate determination.

The study site (276 ha) was selected nearby Rišňovce village, which is one of traditional pilot areas for erosion research in Slovakia (Fig. 1). It is situated in central part of Nitrianska Hilly Land, Western Slovakia. This area is built by loess and it belongs to most important agricultural areas of Slovakia. The altitude ranges from 160 to 220 m above see. Slopes are smooth, with an inclination of 2 - 12^o and

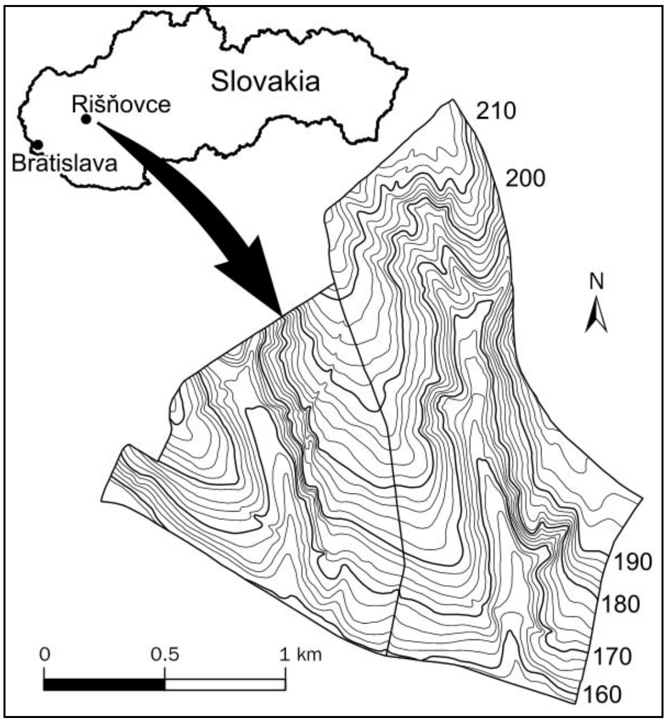

Figure 1. Location of study area.

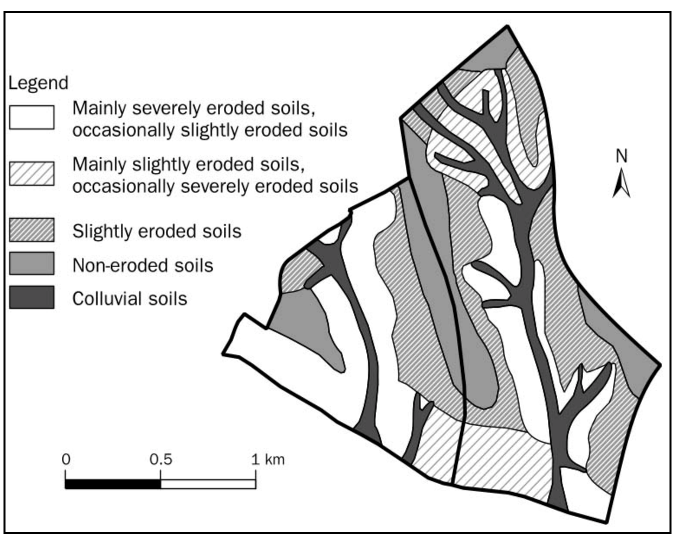

Figure 2. Map of eroded soils based on conventional field survey.

length of 200 - 1200 m. Mean annual temperature is 8 - 9^{o}C. Precipitations reach 550 - 650 mm.year^{-1}, with rainy season from May to July. Highly erosive rains are rare (usually 2 - 3 times per year). The soilscape is dominated by Typic Haplustolls and Typic Haplustalfs and strongly eroded slopes are occupied by Typic Calciustepts (USDA, 1998). Typic Haplustolls have decalcified mollic epipedon (10 YR 3/3). Typic Haplustalfs have an ochric epipedon with color close to the limit for mollic epipedon (10 YR 4/3) and argillic Bt-horizon. C-horizons of all soils are light in color (10 YR 5.5/3.5) and usually strongly calcareous (20 - 27 % of $CaCO_3$). The texture is silt loamy for all soils. The clay content of topsoil is 20 - 28 %, silt 53 - 62 % and sand 16 - 26 %. The subsoil is slightly coarser. Soil reaction is neutral to weakly basic (pH_{H2O} is 6.7 – 7.8). Organic carbon ranges from 0.85 % in ochric epipedons to 1.35 % in mollic epipedons. The land use at study site is very uniform. All area is occupied by arable land. The crop rotation is dominated by winter wheat, maize, spring barley, sunflower, rape, alfalfa, and pea.

The study area is strongly affected by erosion. The first map of eroded soils was done by conventional methods (Fig. 2). It was derived from Soil map of Rišňovce (Fulajtár, 1991). Eroded soils were mapped in combination with non-eroded soils in a form of associated mapping units.

RESULTS AND DISCUSSION

Detection of eroded soils from aerial photographs

The strongly eroded soils are visible on aerial photographs in the form of bright patterns (Fig. 3a). The photographs were scanned, georeferenced and mounted to photomosaic. The erosion patterns were delineated by vectorization on the screen (Fig. 3b). The result showed up, that the main problem of this approach is the erosion detection at parcels covered by vegetation. This can be seen in southwest corner of the study area, which is covered by alfalfa. At this parcel the eroded pattern is not visible. This problem can be avoided either by using several sets of photographs taken in different time periods or by taking the photographs at early spring or in autumn, when the majority of the land is bare. However, the later step does not solve the problem entirely because in southern Slovakia a certain portion of the land is always under the crop.

The second problem is the occurrence of bright patches not associated with erosion, which can be termed "false erosion" patterns. They result from sandy texture, poor organic matter content, dry topsoil, and human activity mixing the soil material from topsoil and subsoil. The false erosion patterns can be easily distinguished from true erosion as they are not linked to topography and their shapes are different. For their identification, the stereoscopical observation of photographs is very helpful and if some patches remain doubtful, they can be verified in field. Some false erosion patterns were identified in the Rišňovce surrounding (Fulajtár, 1994a), but in the study area presented in Fig. 3 they were not identified.

Another problem is the subjectivity of delineation. The spectral reflectance of eroded soils depends on the level of soil degradation and it changes gradually. When vectorizing the erosion patterns, the operator should decide where exactly the boundary of eroded area should be placed. It is obvious, that this decision is subjective and two operators working in one area would produce slightly different erosion regions. Moreover, the appearance of erosion patterns on two different parcels is not equal because the spectral reflectance of land depends not only upon soil erosion. While at one parcel with certain soil moisture and certain organic matter content already a weakly eroded soil can be visible, at another parcel with different soil moisture and organic matter content the soil should be more eroded to be visible. Therefore, the erosion patterns delineated at different parcels may represent the regions with slightly different level of erosion degradation.

The last question is the possibility to distinguish several categories of eroded soils. Considering the gradual change of color according to the level of soil degradation, it should be theoretically possible, but the subjectivity of the delineation which is at acceptable level when only two categories were distinguished (eroded and non-eroded soils), rose considerably when more categories were distinguished.

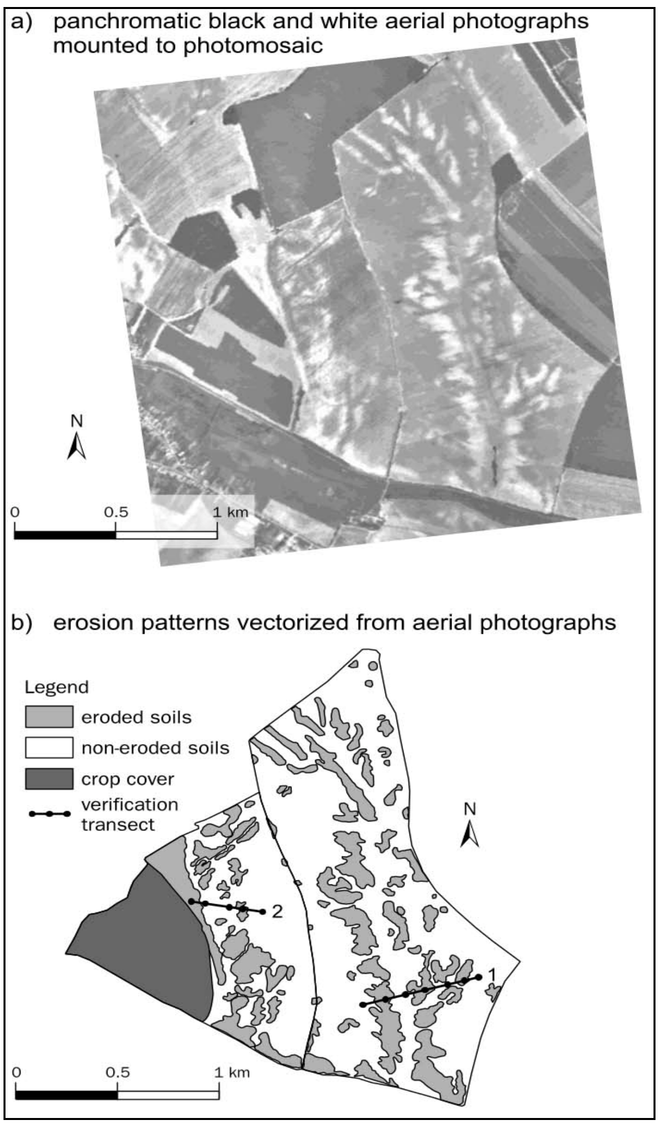

Figure 3. Detection of eroded soils from aerial photographs.

Detection of eroded soils from SPOT PAN image

The erosion patterns appear on SPOT PAN image in a form of bright patterns very similar to patters on aerial photographs although the resolution of aerial photographs is better and the erosion patterns on photographs are finer (Fig. 4a). Two approaches of erosion detection were tested - visual interpretation similar to interpretation of aerial photographs and image classification.

The visual interpretation of SPOT PAN image is shown on Fig. 4b. The vectorization of satellite image has two important advantages compared to vectorization the aerial photographs. First, the satellite image covers a much larger area, which makes the manipulation and geometrical correction easier. The second advantage is the possibility to use the stretching capability of software, which enables to enhance or reduce the color contrast of the image. Such manipulation allows adjusting the contrast at each parcel separately to make the erosion patterns better visible. Several versions of image with different stretching can be printed and in field it can be found out, which stretching reflects the real erosion patterns at particular parcel better. The proper stretching can be evaluated also according to the continuity or discontinuity of erosion patterns at parcel boundaries.

The stretching helps to overcome some limitations of aerial photographs, mainly it improves the poor visibility of the erosion patterns under the vegetation cover. The parcel in southwest corner of the study area is overgrown by young and sparse winter wheat (image scanned at mid March) under which the erosion patterns are weakly visible (Fig. 4a). With the aid of stretching their visibility was enhanced.

The image classification was done according to procedure described in the chapter on material and methods. At first the stratification was done. The study area comprise of five parcels with three different land covers - winter wheat, stubble from previous year and bare soil. These five parcels were separated to three strata. First stratum comprised of two parcels with winter wheat, second stratum was represented by only one parcel with stubble and the third stratum involved remaining two parcels with bare soil. The second step was an uncontrolled image classification done for each stratum representing different crop cover separately. Considering that two erosion categories were needed (eroded soils and non-eroded soils), the initial number of classes was stated to four. Next, these classes were grouped using the uncontrolled aggregation. The resulting patterns were compared to original non-classified image as well as to results of visual interpretation. The uncontrolled aggregation did not match the bright patterns representing the eroded soils on SPOST image properly. Therefore the controlled aggregation was applied (Fig. 4c). The result of this procedure matches the erosion patterns much better than the uncontrolled aggregation, although not as good as the visual interpretation.

The main advantage of the image classification is speeding up the processing of data, what would be appreciated mainly when large areas should be mapped. Another important advantage is, that the image classification is an exact quantitative procedure, which helps to avoid the subjectivity of manual interpretation. If two operators would use the same procedure and the same number of classes, the results should be equal.

Verification of the results

The erosion patterns appear differently on aerial photographs and SPOT PAN image, because the spectral reflectance of the land surface depends on many variables (soil properties, vegetation, atmospheric parameters and capabilities of scanning device), some of which are time-variant. This primary variability is enhanced by secondary variability rising from the data processing. Therefore it was expected, that the erosion patterns delineated from different media by the same method or from the same medium by different methods would be not equal.

The verification of obtained erosion maps was done firstly by the visual assessment based on mutual comparison of original media and delineated erosion patterns and later it was supported by field survey. The field verification was based on auger observations arranged to three transects (Table 1). First transect was cutting the area, where the patterns obtained by all three methods match well together. The second transect represents the other case, when the patterns vectorized from aerial photographs and from SPOT image differ and the third transect shows the area, where the patterns obtained by visual interpretation and by classification of SPOT image differ.

a) SPOT PAN satellite image

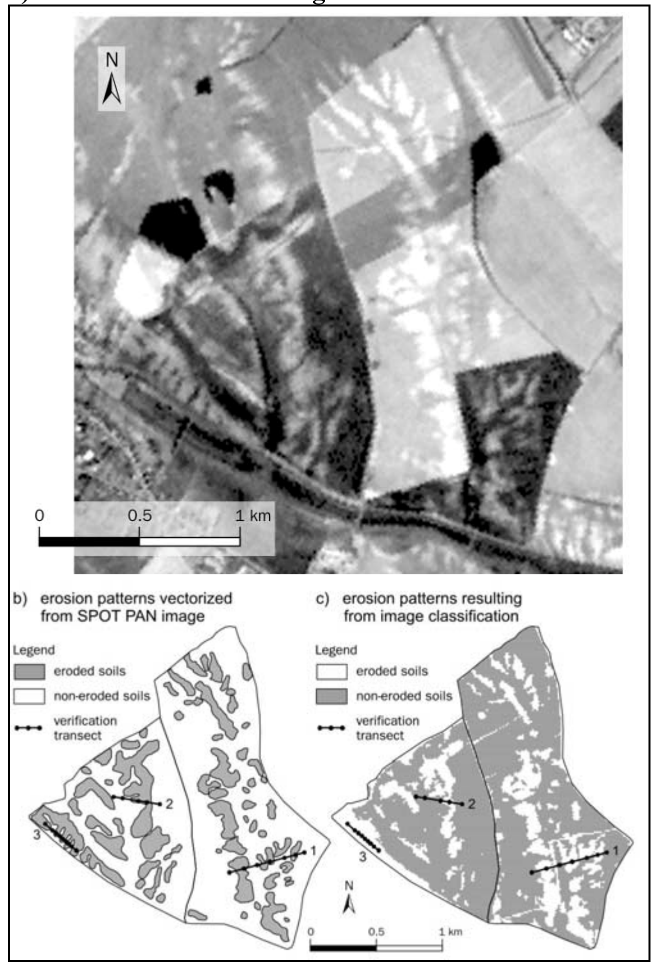

Figure 4. Detection of eroded soils from SPOT PAN image.

Table 1. Verification of delineated patterns by field survey

		Control Point									
RSM	EDM	1	2	3	4	5	6	7	8	9	True (%)
-	FO	N	E	N	E	N	E	N	-	-	100
AP	VI	N	E	N	E	N	E	N	-	-	100
SI	VI	N	E	N	E	N	E	N	-	-	100
SI	IC	N	E	N	E	N	E	N	-	-	100
-	FO	E	N	N	E	N	-	-	-	-	100
AP	VI	E	N	N	E	N	-	-	-	-	100
SI	VI	N	N	E	E	N	-	-	-	-	60
SI	IC	N	N	E	E	N	-	-	-	-	60
-	FO	E	N	E	N	E	N	E	N	E	100
AP	VI					**Crop cover**					-
SI	VI	E	N	E	N	E	N	E	N	E	100
SI	IC	E	E	E	E	E	E	E	E	E	56

Explanation: AP - aerial photographs; EDM - erosion detection method; E - eroded soil; FO - field observation; IC - image classification; N - non-eroded soil; RSM - remote sensing medium; SI - SPOT PAN image; T – transect; VI - visual interpretation.

The verification showed that the erosion patterns vectorized from aerial photographs are most accurate. The patterns vectorized from SPOT image are less detailed, because of its lower resolution, which is 10 m. This is not fully sufficient as some erosion areas are 10 - 20 m wide and on the SPOT image they are represented only by 1 - 2 rows of pixels. The least precise is the result of image classification.

CONCLUSION

The aerial photographs and SPOT PAN images provide valuable data for erosion mapping. The results of all three presented approaches of erosion detection are far better compare to conventional mapping based on field survey (compare Fig. 3b, 4b,c to Fig. 2). The best results were obtained by visual interpretation of aerial photographs. However, for routine mapping of large areas the visual interpretation of SPOT PAN images would be the most reasonable procedure, despite of lower resolution. This approach is more effectual, it enhances the possibilities for erosion detection under the crop cover, and its accuracy is for practical application in land management more than sufficient.

The result of image classification is also usable, despite of its lower accuracy. This method needs more research, but it is promising for future, thank to its potential for reduction of the interpretation subjectivity. Its accuracy can be improved by increasing the initial number of classes.

After successful testing of erosion detection from remote sensing data in Rišňovce Pilot Area, the visual interpretation of both aerial photographs and satellite images became routinely used in Slovakia. Since now first hotspot agricultural areas were mapped at a scale of 1:50000 (Fulajtár and Janský, 2001, Sviček, 2000). In future the research should be aimed to reduction of the interpretation subjectivity and to possibilities of distinguishing several categories of eroded soils. For this purpose the assessment of multispectral data can be eligible.

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