

ELABORATION OF PRODUCTS DERIVED FROM EO DATA AND GIS INFO-LAYERS FOR FLOODING RISK ANALYSIS

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Abstract: The risk of flooding due to runoff is a major concern in many areas around the globe and especially in Romania. In the latest years river flooding and accompanying landslides, occurred quite frequently in Romania, some of which isolated, others-affecting wide areas of the country's territory.

The modern management of spatial data related to river flooding largely relies on the functional facilities supplied by the Geographic Information System (GIS) info-layers, combined with Earth Observation (EO) data-derived information, Digital Elevation Models (DEM) and hydrological modeling.

The paper assumes this multidisciplinary approach, in view to establish a methodology, which should further allow the elaboration of products useful for flooding risk analysis, such as: more accurate updated maps of land cover/land use, comprehensive thematic maps at various spatial scales with the extent of the flooded areas and the affected zones, maps of the hazard prone areas, etc.

There are stressed the facilities supplied by the geo-referenced information and the satellite images to manage floodings during their characteristic phases: before, during and after floodings; accent is laid on the pre and post-crisis phases.

Some applications developed in hydrographical basins of Romania Arges and Crisuri are presented.

Keywords: flood, risk, vulnerability, remote sensing, satellite, GIS.

AUSARBEITUNG VON PRODUKTEN AUF GRUND DER EO-DATEN UND DER GIS-INFO-KARTEN FÜR DIE ANALYSE DER ÜBERSCHWEMMUNGSRIKOS

Zusammenfassung: Das Risiko der Überschwemmungen infolge der Niederschläge ist ein großes Problem in vielen Gegenden der Erde und besonders in Rumänien.

In den letzten Jahren finden ziemlich oft Überschwemmungen der Flüsse statt, von Erdbeben begleitet, von denen manche isoliert sind, aber andere breite Gebiete des Landes.

Das moderne Management der Daten von Satelliten betreffen die funktionellen Lösungen, die von dem Geographic Information System (GIS) – Info – Karten bekommen werden, verbunden mit den Daten der Erdebeobachtung (EO), Digital Elevation Model (DEM) und der hydrologischen Modellierung.

Die Arbeit bietet ein multidisziplinäres Herangehen an, um eine Methodologie festzustellen, die in der Zukunft zu nützlichen Lösungen führen, betreffs die Risiken der Überschwemmungen, wie z. B.: mehrere präzisere und aktuelle Karten des bedeckten Bodens oder des Bodengebrauchs, thematische Karten in verschiedenen Maßstab mit der Ausdehnung der überschwemmten Gebieten bzw. der betroffenen Zonen und der gefährlichen Zonen.

Hier werden die Überschwemmungen während ihrer wichtigen Phasen behandelt: vorher, währenddessen und nachher. Als Grundlage dafür dienen die Informationen und die Bilder von den Satelliten. Der Schwerpunkt ist aber die Phase vor und nach der Krise.

Manche Anwendungen aus den hydrologischen Becken Rumaniens Arges und Cris werden hier dargestellt.

Schlüsselwörter: Überschwemmung, Risiko, Schwachpunkte, Fernerkundung, Satellit, GIS.

1. Introduction

Ever since the first satellite observations of the Earth, numerous studies have been achieved using information from the satellite systems and the facilities of GIS technology in the topic of managing flooding connected phenomena. Satellite images are objective information sources, available in time and relatively cheap, for the determination of parameters necessary to monitor and assess floods and their consequences (Wang et al., 1995).

The main contribution of EO derived information could be envisaged at the level of mapping aspects. EO satellites can provide information necessary to elaborate cartographic documents, important for hazard and vulnerability mapping. EO derived data are useful to locate, measure and spatially represent up-to-date information such as: flooded areas, parameters on vegetation, human presence and terrain properties, which are directly used in the decision - making process.

In order to obtain high level thematic products the EO useful extracted data must be integrated with other non-space ancillary data (topographical, pedological, meteorological data) and hydrologic/hydraulic models outputs. So, the management of data helping to monitor the generated high floods largely relies on an integrated approach using the functional facilities supplied by the GIS (Harms et al., 1996).

This approach may be used in different phases of establishing the sensitive areas such as: the management of the database - built up from the ensemble of the spatially geo-referenced information; the elaboration of the risk indices from morpho-hydrographical, meteorological and hydrological data; the interfacing with the models in order to improve their compatibility with input data; recovery of results and the possibility to work out scenarios; presentation of results as synthesis maps easy to access and interpret, additionally adequate to be combined with other information layouts resulted from the GIS database.

2. Study areas

The study areas were represented by some Carpathians basins of Romania affected by extreme floods.

2.1. The Arges basin

The Arges hydrographic basin is affected by flooding as ascertained by the frequency of these phenomena: 1972 – 1973, 1975, 1979, 1983, 1991, 1997, 1998. This area is so much the more critical one, considering that it comprises the capital, as well as several other important economic centres. As regards the results damages, the high flood of March 29 - April 10 1997, alone affected nearly 600 households and annexes, over 4000 ha of arable land, 4 bridges, more than 40 footbridges and 40 Km of roads, along with important hydrotechnical constructions.

Situated in the south of the country, the Arges river, its tributaries included, constitutes one of the most important hydrographic basin in the country with respect to its hydro-energetic potential and the water supplies of the industrial centres and crop lands. Through the position it occupies in a physico-geographic ensemble with specified characters, with a moderate continental climate, sufficiently humid in the mountain areas and drier in the plain, is playing a large variety of the relief and lithology, the Arges river hydrographic basin has a complex hydrological regime.

2.2. The Crisul Alb basin

In the Crisul Alb basin, near the Romanian – Hungarian border, there can be registered precipitation amount between 600 and 800 mm/year in the plain and plateau areas and in the mountain one, over than 1200 mm/year. In other areas of the country, the precipitation amount is smaller, so that in the plain area it registers on amount between 400 and 600 mm/year while in the mountain area it is between 1000 and 1200 mm/year. The western region of Romania registers the highest values of the multiannual precipitation. This distribution can be explained by the fact that humid air masses brought about by fronts from the Icelandic Low, frequently come in this area. The orography of the area (Apuseni

Mountains) amplifies the precipitation on the western side of the mountain chain; so that the Crisuri Rivers Basin is frequently affected by large water amount in short time intervals. In the last years, the downpours registered a serious increase in this area.

The frequency and importance of floods in the region require work to reduce such damage, and better facilitate efficient monitoring by the organizations in charge of natural hazards, such as government agencies, civil protection authorities or municipalities. For example in in the spring of 2000 two large floods brought important damages of more than USD 20 millions. These losses included damages to 807 houses, 196 km of roads and railways, 170 bridges, 35 objectives social economic and 84 hydraulic structures, and loss of 134 domestic animals.

3. Structure, attributes and functions of GIS database

The database was structured as an ensemble of file-distributed quantitative and qualitative data.

Organizing the files was focused on a relational structure as information thematic layouts. With this approach, spatial objects may be described through three main property classes: those determining the objects position on the Earth surface, those establishing spatial relations with other objects and those referring to the spatial objects attributes.

Coding the existing relationships between spatial entities was performed with the help of facilities supplied by the complete topology of the PC ARC/INFO software. The achievement was viewed of a database apt to allow elaborating indices of hydrological risk to flooding, made up of information associated to three main criteria:

- morphology and topography: hydrographic network, dams and channels network, sub-basins, confluence order; hydrographic and/or drainage network density; mean slopes of the sub-basins; mean slopes in different river sections;
- land cover/land use: land impermeability, in-soil water resilience to infiltration;
- vulnerability to flooding: communication ways network (highways, railroads), localities, meteorological, hydrometric stations network and rain measurement points network.

GIS database info-layers have been divided in three large categories:

- those relative static (land topography and altimetry, basin and sub-basin boundaries, the communication ways network, the localities, the network of meteorological and hydrometric stations);
- those with specific dynamic characteristics which required periodical updates, with frequencies of the order of year (land cover/use, hydrographical network, the network of dams and canals);
- those determined by particular events.

The database was connected so as to allow obtaining synthetic representations of the hydrological risk for the Arges basin, through using the risk parameters separately or combined. For instance, there can be considered the mean slopes of the mountainsides, the in-soil water absorption, the water resilience to infiltration and the vulnerability degree. The advantage consists in that the system allows greater parameters combination diversity, allotted with various weights, and associated to the mentioned three main criteria.

4. Elaboration of products for flooding risk analysis

Within the framework of flood surveying, optical and radar satellite images can provide up-to-date geographical information. Integrated within the GIS, flood derived and landscape descriptive information are helpful during their characteristic phases of the flood (Tholey et al., 1997):

- before flooding, the image enables the description of the land cover of the studied area under normal hydrological conditions;
- during flooding the image data set provide information on the inundated zones, flood map extent, flood's evolution;
- after flooding, the satellite image point out the flood's effects, showing the affected areas, flood deposits and debris, with no information about the initial land cover

description unless a comparison is performed with a normal land cover description map or with pre-flood data.

The products useful for flooding risk analysis, referred to: accurate updated maps of land cover/land use, comprehensive thematic maps at various spatial scales with the extent of the flooded areas and the affected zones, maps of the hazard prone areas.

4.1. EO data processing and analysis

Optical (LANDSAT-TM, IRS-PAN/LISS, SPOT-AN/XS) and radar satellite data (RADARSAT) have been used to perform the analysis for inventory purposes and different kind of flood related thematic information.

A series of specific processing operations for the images were performed, using the ERDAS Imagine software; geometric correction and geo-referencing in the stereographic 70 map projection system (using control points on the 1/50 000 scale map), image improvement (contrast enhancing, slicking, selective contrast, combinations between spectral bands, re-sampling operation), statistic analyses (for the characterization of classes, the selection of the instructing samples, conceiving classifications).

Optical high resolution data have been used to perform the analysis for the inventory purposes under normal hydrological conditions as well as for determining the hydrographic network. The radiometric information contained in these images allows the derivation of both biophysical criteria and those from human activity, through supervised standard classification methods or advanced segmentation of specific thematic indices. Once extracted, these geographical information coverages were integrated within the GIS for further water crisis analysis and management.

The interpretation and analysis of remotely sensed data in order to identify, delineate and characterize flooded areas was based on relationships between physical parameters such as reflectance and emittance from feature located on the surface: reflectance and/emittance decreases when a water layer covers the ground or when the soil is humid; also reflectance and/emittance increases in the red band because of the vegetation stress cause by moisture; reflectance and/emittance changes noticeably when different temperatures, due to thick water layer are recorded.

In the microwave region the water presence could be appreciated by estimating the surface roughness, where water layers smooth surfaces dielectric constant is then heavily correlated to soil water content. In case of radar images the multitemporal techniques was considered to identify and highlight the flooded areas. This technique uses black and white radar images of the same area taken on different dates and assigns them to the red, green and blue colour channels in a false colour image. The resulting multitemporal image is able to reveals change in the ground surface by the presence of colour in the image ; the hue of a colour indicating the date of change and the intensity of the colour the degree of change. The proposed technique requires the use of a reference image from the archive, showing the « normal » situation.

4.1.1. The land cover/land use mapping

The methodology for the achievement of the land cover/land use from medium and high-resolution images developed within the Remote Sensing & GIS Laboratory of NIMH (Stancalie et al., 2000), is based on the observation of the following requirements:

- the structure of this type of information must be at the same time cartographic and statistic;
- it must be suited to be produced at various scales, so as to supply answers adapted to the different decision making levels;
- up-dating of this piece of information must be performed fast and easily.

The used methodology implies following the main stages below:

- preliminary activities for data organizing and selection;
- computer-assisted photo-interpretation and quality control of the obtained results;
- digitization of the obtained maps (optional);
- database validation at the level of the studied geographic area;

- obtaining the final documents, in cartographic, statistic and tabular form.

Preliminary activities comprise collection and inventorying of the available cartographic documents and statistic data connected to the land cover: topographic, land survey, forestry, and other thematic maps at various scales.

To obtain the land cover map, images used must have a fine geometrical resolution and rich multispectral information. That is why the data preparation stage consisted in merging data obtained from the panchromatic channel, which supply the geometric fineness (spatial resolution of 5 m for the IRS, 10 m for the SPOT), with the multispectral data (LISS for IRS, XS for SPOT), which contain the multispectral richness.

A series of specific processing operations for the images were performed with the ERDAS Imagine software. Those operations included: image improvement (through using the histogram, contrast enhancing, slicking, selective contrast, combinations between spectral bands, re-sampling operation), statistic analyses (for the characterization of classes, the selection of the instructing samples, conceiving classifications). The French Arkemie software was also used in view to improve the results obtained from the operations of classification over parcels.

The computer-assisted photo-interpretation finalizes in the delimitation of homogeneous areas from images, in their identification and framing within a class of interest. Discriminating and identifying the different land occupation classes rely on the classical procedures of image processing and leads to a detailed management of the land cover/land use, followed by a generalizing process, which includes:

- identification of each type of land occupation, function of the exogenous data, of the "true-land" data establishing a catalogue;
- delimitation of areas suspected to represent a certain unity of the land;
- expanding this delimitation over the ensemble of the image areas, which display resembling features.

Validation of results from photo-interpretation, mapping (by checking through on land sampling at local and regional level) and building up the database aims at knowing the reliability level and the precision obtained for the delimitation of the units and their association to the classes in the catalogue.

The satellite based cartography of the land cover/land use is important because it makes possible periodical updating and comparisons, and thus contribute to characterize the human presence and to provide elements on the vulnerability aspects, as well as the evaluation of the impact of the flooding.

The figure 1 presents the updated land cover/land use maps (9 main classes: artificial (built) surfaces (AS), open spaces with little or no vegetation (OS), vineyards and orchards (VO), agricultural lands (AL), forests (F), pastures and natural grasslands (P), heterogeneous lands belonging to households (LH), humid surfaces (HS), lakes and water bodies (WB)) for the Arges basin, characterized by a large variety of the land cover/use classes. The product was obtained using IRS/PAN and IRS/LISS images from 9 April and 23 September 1999.

The land cover maps are useful to classify the terrain function of the main types of land cover, thus allowing their characterization function of the land impermeability degree, of their absorption capacity or resilience to in-soil water infiltration. The notion of terrain impermeability was connected to the necessity to determine the absorption capacity and resistance to in-soil water infiltration. It must be mentioned that these parameters represent "potential capacities", having in view that the dry soil hypothesis is considered.

For example, in view to establish the impermeability degree, specific coefficients - , within a scale ranging from 0 to 1 - have been assigned to the identified land cover/use classes (table 1). These coefficients allow determining the mean impermeability coefficient by sub-basin, weighted with their mean slopes.

Table 1. Impermeability coefficients associated to the main land cover and land use classes in the Arges basin

Land cover/land use class	F	AL	VO	LH+P	OS	HS	AS
Impermeability coefficient	0.4	0.5	0.7	0.75	0.8	0.9	1.0



Figure 1. The land cover map for the Arges basin, obtained from IRS images

In view to establish the water absorption capacity over the basin surface, the land cover and use classes were regrouped by a number of four classes, to which specific coefficients have been assigned (table 2): artificial surfaces (AS), agricultural lands (AL), vineyards and orchards (VO), pastures and grass lands (P), lands belonging to households (LH). The allotted coefficients represent the precipitation amount, which a field is able to absorb.

Table 2. Water absorption capacity values associated to the main land cover and land use classes in the Arges basin.

Land cover/ land and use class	AS	AL	VO	LH + P
Water absorption capacity (mm)	60	300	280	360

These coefficients are related with a runoff delay factor: the higher the coefficient, the higher the soil capacity to absorb water; also, the higher the water absorption capacity at the level of a spatial unit, the higher the precipitation necessary in a time unit for runoff occurrence.

The analysis concerning the water absorption capacity at the sub-basin level has allowed establishing a hierarchy of the basins function of their capacity to retain the water before the occurrence of the surface runoff.

The figure 2 presents the map of the water absorption capacity distribution according to main types of land cover classes in the Arges basin.

The satellite-based mapping approach proved to be very efficient for the elaboration of detailed land cover/land use maps. These products are useful to analyze certain hazard aspects of flooding.

4.2 Methodology for the identification and mapping of the flooded areas

The methodology for the identification, determination and mapping of the areas affected by floods is based on the supervised classification procedure of the satellite images. The multi-temporal analysis and combination of the land cover/use classes allow the identification of the area covered by water (included the permanent water bodies) and then of the flooded areas (SCOT, 2000).

The figure 3 presents the situation of the April 2000 flood event in the Crisul Alb basin: the flooded area was identified on the SPOT image of 18 April 2000 (A) and then the flood boundaries were superimposed on the IRS PAN + LISS derived map (B).

This approach is very useful especially after the crisis for damages inventory and for recovery actions, taken to re-building destroyed or damaged facilities and adjustments of the existing infrastructure.

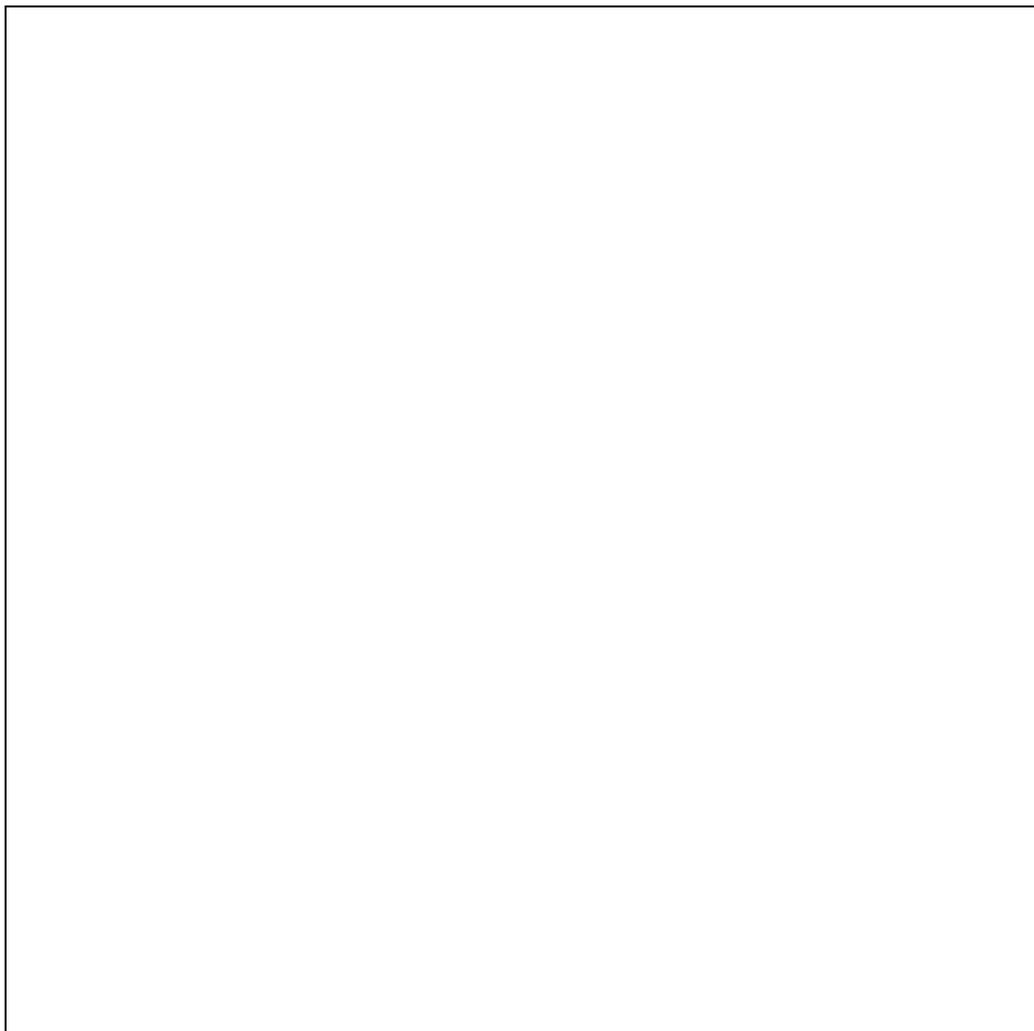


Figure 2. Water absorption capacity distribution in the Arges basin

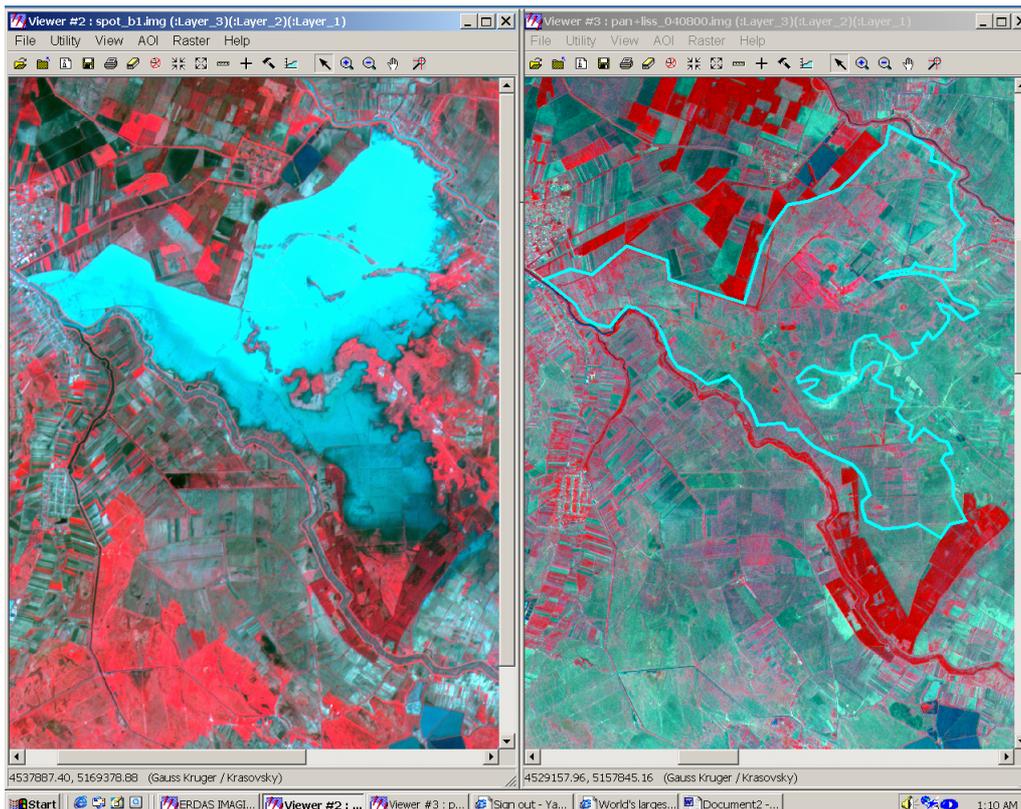


Figure 3. Crisul Alb basin: flood extension - from the SPOT image of 18 April 2000 (A) and the area affected superimposed on the IRS derived classified map (B)

Using the methodology for the identification and mapping of the flooded areas is possible to monitor and investigate the flood evolution during different phases. In the figure 4 is presented the flood evolution on the Crisul Alb River during the April 2000 flood, observed on SPOT and IRS satellite images.

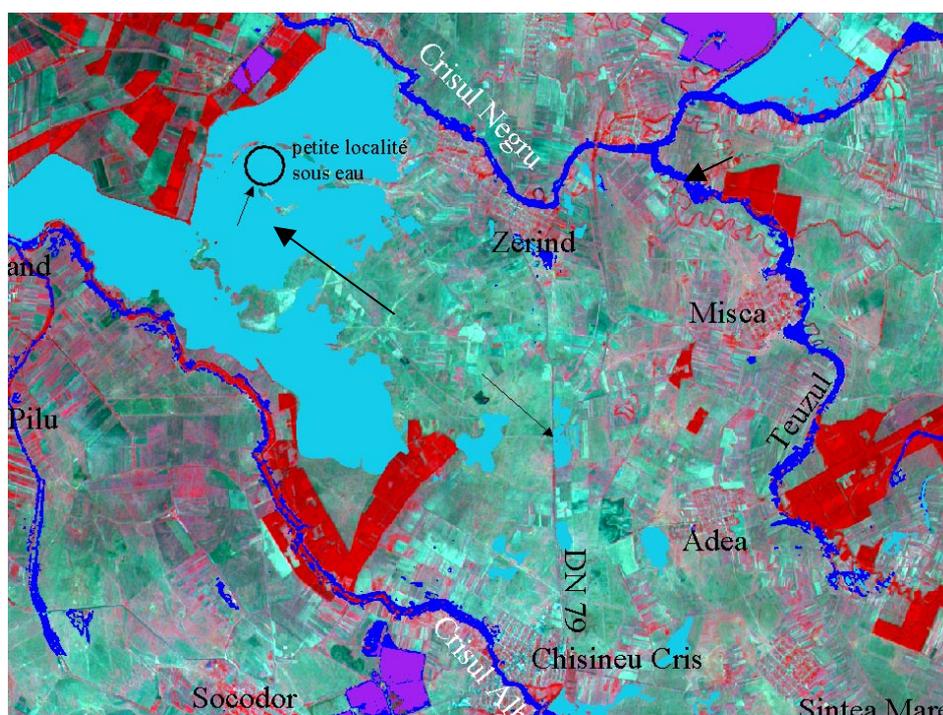


Figure 4. Crisul Alb basin: April 2000 flood evolution observed on the SPOT and IRS satellite images

4.3 Methodology for the flooding risk maps preparation

The assessment of the flooding risk hazard requires a multidisciplinary approach; coupled with the hydraulic modelling, the contribution of geomorphology can play an exhaustive and determining role using the GIS tools.

In order to obtain the flood risk map for the test-area, a important step refers to construction of the DTM and its integration, together with the land cover/land use maps in the GIS using a common cartographic reference system.

The DEM was realized after the following steps:

- scanning the maps. 12 plans at 1:5000 scale and 3 topographic maps at 1:25000 were scanned at 300 dpi resolution;
- geo-referencing the maps. The scanned images were geo-referenced in STEREO 70 projection;
- colour separation. Each raster information layer is extracted as a linear image (black & white without gray tones);
- vectorization of raster images.
- merging the maps;
- generating a triangulated irregular network (TIN) model.

In a TIN the point density on any part of the surface is proportional to the variation in terrain. A surface is a continuous distribution of an attribute over a two-dimensional region. TIN represents the surface as contiguous non-overlapping triangular faces. The surface value is estimated in this way for any location by simple (or polynomial) interpolation of elevation in a triangle. As elevations are irregularly sampled in a TIN, it is possible to apply a variable point density to areas where the terrain changes sharply, yielding an efficient and accurate surface model. A TIN preserves the precise location and shape of surface features.

Various morphological criteria may be extracted from a DEM, designed using topographical maps and geodetic measurement criteria, such as altitudes, slopes, exposures, transversal profiles and thalweg locations. All these parameters are useful to evaluate the local or cumulated potential flowing into a zone of the basin. This approach is also useful to get a realistic simulation of floods, taking into account the terrain topography, the hydrological network and the water levels in different transversal profiles on the river, obtained from the hydraulical modelling.

Using the GIS database that include the DTM, the land cover / land use maps and the vector info-layers (hydrographical, dams and canals networks, the communication and localities network etc) several outputs of hydraulic simulations could be superimposed in order to elaborate the risk maps to flooding.

In the figure 5 an example of a risk map for a test area of the Arges basin is presented; the surface covered by water, resulted from a hydraulic scenario of flood with 0.1% probability and delimited from the DTM, was merged on the land cover/land use map.

5. Conclusions

Considering the necessity to improve the means and methods to assess and monitor flooding, the paper presents the capabilities offered by remotely sensed data and GIS techniques to manage flooding and the related risk. The applications were developed on the Arges basin in Romania.

Although satellite sensors cannot measure the hydrological parameters directly, remote sensing can supply information and adequate parameters to contribute to identify and map the hydrological risk at the basin level (Puyou-Lascassies et al., 1996).

The basic concepts of the creation of products useful for flooding risk analysis (maps of land cover/land use, thematic maps of the flooded areas and the affected zones, flooding risk maps) can be summarized in the following stages:

- preparation of the EO data: radiometric, geometric correction and other basic image processing;
- combination of the interpretation techniques: automated and photo-interpretation tools, as well as radiometric techniques;

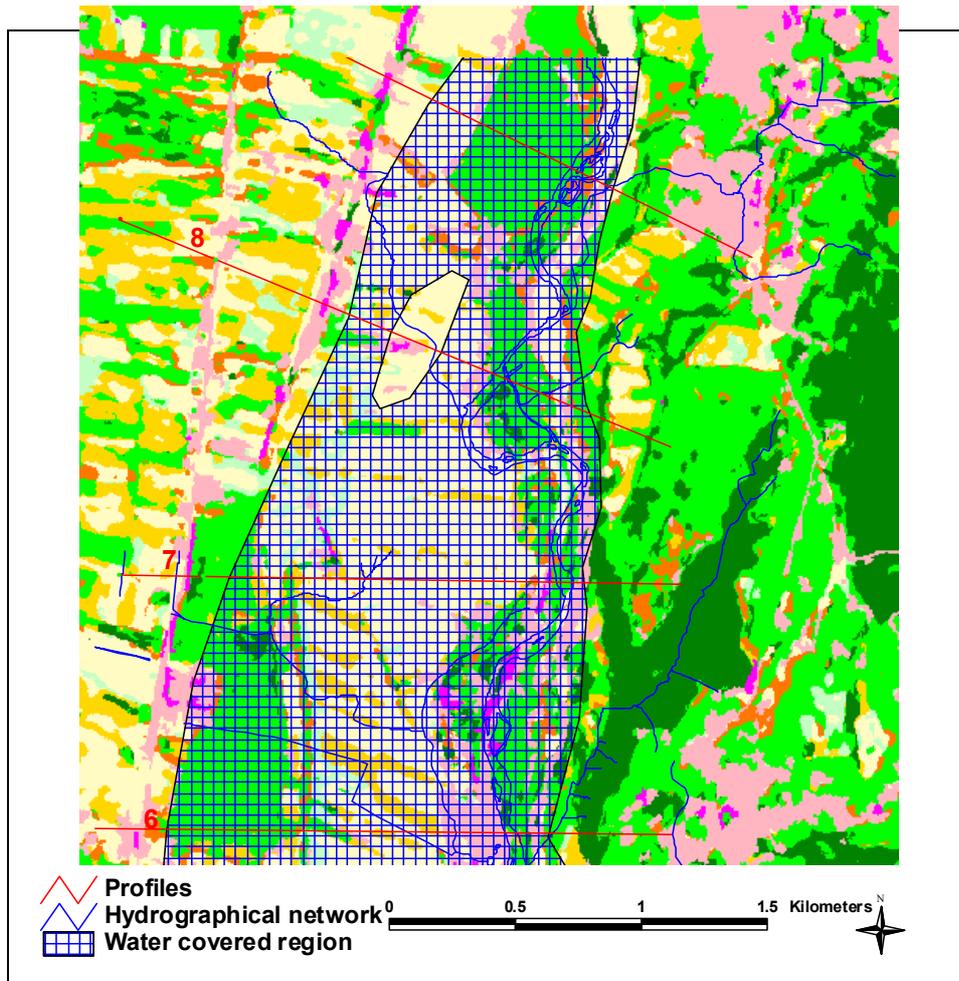


Figure 5. The risk map for a sensible zone in the mid part of the Arges basin

- multi-sensor approach: make the analysis process easier and provide the opportunity to improve the quantity and quality of the information obtained;
- multi-temporal approach: gives the possibility to monitor low frequency (land modification) and high frequency phenomena (evolution of the floods boundaries);
- integrated approach: the high level products are based on the EO derived information combined with other ancillary data, hydrologic/hydraulic models outputs using the GIS facilities.

The GIS database, was useful for the elaboration of the flooding hydrological risk indices and gas allowed obtaining synthetic representations of the hydrologic risk, through separate or combine use of the risk parameters, as well as for interfacing with the hydrological models in view to improve them as regards compatibility with input data, recovering results and the possibility to achieve scenarios.

The products derived from EO data and GIS info-layers (land cover/land use digital maps, satellite-derived maps, image maps with integration of local GIS data, parameters derived from satellite images and GIS database, flood hazard maps for several probabilities of the maximum discharge occurrence) could be used in several category actions:

- in the preparedness/warning actions, taken to insulate people or infrastructure from specific hazard events, to plan for possible scenarios to minimize the potential impacts and subsequently to establish the necessary infrastructure to either prevent it or minimize its impacts.
- In the recovery actions for pinpointing locations and the degree of damages, for re-building destroyed or damaged facilities, for the insurance companies as a up-to-date information to settle claims.

Hazard data obtained on the local scale can be combined with vulnerability data on population, land use, type of buildings, infrastructure (roads, railways, bridges, hydraulic structures, etc.) and socio-economic activities in order to assess the risk and to create/update flood risk maps.

6. References

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