FLOOD HAZARD ASSESSMENT AND MONITORING USING GEOGRAPHIC INFORMATION AND REMOTELY SENSED DATA

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ABSTRACT

Floodings are an important risk in many areas around the globe and especially in Romania. In the latest years floodings occurred quite frequently in Romania, some of which isolated, others were affecting wide areas of the country's territory.
The paper assumes a modern approach for the flooding risk indices, associated to the physic-geographical, morpho-hydrographical and vulnerability characteristics of a region, in view to establish a methodology which should further allow to determine the flooding risk, using representatives indices at a scale compatible with a synthetic representation of the territory. There are stressed the facilities supplied by the Geographic Information System (GIS) and the remotely sensed data to manage flooding during their characteristic phases: before, during and after flooding. Accent is laid on the pre and post-crisis phases.
The application was developed for the Arges hydrographic basin in Romania, a critical area, keeping in mind that it withholds many localities, including the capital and also important economic centres.

KURZFASSUNG

Fluten sind ein groβes Risiko in vielen Gegenden der Welt und ins besonders in Rumanien. In den letzten Jahren gaben es haufig Fluten in Rumanien, manche von denen isoliert, aber andere hatten einen negativen Einfluβ auf groβe Landoberflachen.
Dieses Dokument stellt eine neue und moderne Anlegweise, zusammen mit des physisch-geographischen, morpho-hydrographischen und Vulnerabilitatseigenschaften einer Region, in der Perspektive der Erstellung einer Methodologie die zukunftig erlauben wird das Flutenrisiko zu bestimmen. Dieses sollte unter Anwendung von representativen Indikatoren auf einer Skala die kompatibel mit der symetrischen Representierung des Territoriums erfolgen. Man kennzeichnet somit die bedeutungsvollen Erleichterungen des geographischen Informationssystems (GIS) und die Kapazitat der fernerfaβten Daten bezuglich des Flutenmanagements in den charakteristischen Phasen: bevor, wahrend und nach den Fluten. Akzent wird auf die Vor- und Nachkriesenphasen.
Die Anwendung wurde fur das hydrographische Becken Arges, Rumanien durchgefuhrt. Es handelt sich um eine kritische Gegend wenn man daran denkt daβ es hier viele Ortschaften und wirtschaftliche Zenten, gibt.

1. INTRODUCTION

Floodings and the accompanying landslides (mainly caused by abundant precipitation) affect and destroy houses and households, bridges, roads, railroads, telephone and power network, crops, water supply systems, hydrometric installations, leading to dysfunction in the warning and hydrological forecast activity.

Eversince 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 floodings and their consequences (Wang et al., 1995). Based at the beginning on the use of LANDSAT data, this activity gained peculiar interest once the possibility yielded for a combined use of remote sensing data from the optic and microwave domain respectively.

The management of data helping to monitor the generated high floods largely relies on the functional facilities supplied by the GIS systems, combined with satellite image-data and the hydrological models (Fellah and Tholey, 1996). This approach may be used in the differential phases of establishing the sensitive areas, such as: management of the database built up from the ensemble of the spatially geo-referenced information; elaboration of the risk indices on the ground of the morpho-hydrometrical, meteorological and hydrological data; interfacing with the models in view to improve them into what concerns 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 database.

2. STUDY AREA – ARGES BASIN

The study area represented by 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.

3. WORKING METHOD

Forecasting and monitoring phenomena associated to torrential precipitation is very difficult, one hand because of the nature of these phenomena, characterised through violence and spontaneity and on the other – because of the basins' characteristics (size, geomorphology) which make the propagation time, i.e. the reaction interval, generally very short. In this context, prevention and forecast activities must be based on prior identification and localisation of the sensitive areas. Approaching the previously formulated issue was made at two levels:

- that of the risk degree vis-à-vis the various parameters causing or not floodings;
- that which takes into accounts the human presence in the sensitive areas. This implies to establish the vulnerability degree, defined function of the human and material costs that flooding may induce.

Integrating the notion of risk in quantifying the potential damages proves to be an absolute necessity, determined by the proportion of the human and economic consequences of the phenomenon.

Given the spatial length of the Arges hydrographic basin the work scale was chosen 1:200 000. The elaboration of digital maps concerning the elements of interest to monitoring and assessing floodings and their consequences aimed at answering self evident small scale forecast necessities, but also to supply documents presumed to bring forth a certain number of answering elements, so as to use information regarding soil occupation and territory management.

Having in view the sizes of the Arges basin and its physico-geographical characteristics, as well as the practical and lucrative constraints, the basin was divided into three areas: upper, middle and mower. The acquisition of the cartographic data and elaboration of thematic layouts as part of the GIS system under ARC/INFO software environment, was made corresponding to these three sectors. The system's facilities allow unifying the layouts of the mentioned basin sectors for ensemble representations as well as to combine the different thematic layouts.

The basic entity in hydrology is the sub-basin defined as the geographic environment, which supplies a water flow. The induced hydrological activity depends on its surfaces geological structure and disposition of the hydrographic network, as well as on the climatic and topoclimatic characteristics. In this sense, there was performed the division of Arges basin in its belonging sub-basins.

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 proved to be further helpful before a crisis for flood prevention perspectives, during a crisis for flood detection and mapping and after the crisis for impact assessment and damage evaluation. High and medium spatial resolution satellite images like NOAA-AVHRR, SPOT-HRV and ERS-SAR were used in order to produce different kind of flood related thematic information, depending on the data acquisition time (Tholey et al., 1997) :

- before flooding, the image enables the description of the landcover of the studied area under normal hydrological conditions (assuming that the river's width is compatible with the image's spatial resolution);

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

4. STRUCTURE, ATTRIBUTES AND FUNCTIONS OF GEO - REFERENCED DATABASE

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

The first information group allows describing the basin and sub-basins from the viewpoint of the physico-hydrographical characteristics. Classifications and hierarchizations may be made, function of the mountainside and riverbed slopes, of the confluence orders and network or draining density. Such analysis, vis-à-vis the risk degree associated to one parameter or combination of parameters (risk accumulation) may be performed for each sub-basin, basin sections or at whole basin scale.

As regard the notion of confluence order associated to a sub-basin, this can be defined function of the number of sub-basins it supplies directly or of the ensemble of sub-basins it supplies from upstream. Since the mean slope of a waterflow is generally incorrectly correlated with the mean slope of the mountainsides belonging to the associated sub-basin, both parameters concerning the slope were taken into- account as risk factors.

The second group is useful to classify the sub-basins function of the main types of vegetation cove and land use, thus allowing their characterisation function of the land impermeability degree, of their absorption capacity or resilience to in-soil water infiltration. The notion of soil 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. Certainly, results differ sensibly if the soil is already water saturated at the beginning of the period with precipitation; in this case, coefficients must be modified.

The third group characterises the degree of vulnerability to flooding, being mainly determined by the human presence (associated to localities) in the high-risk areas. It is thought that the vulnerability aspect may be evaluated taking into consideration the existence of inhabited areas in the vicinity of water flows, of dams and other protection hydrotehnical works, of the potential degree of afflicting the communication ways network, etc.

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, associated to the mentioned three main criteria.

The layout of the hydrographic network encompasses the network properly (including the temporary flows), as well as the existing lakes and storages. The basin was divided in 168 sub-basins, along with the basin rests belonging to a confluence or storage.

The layout of the communication ways comprises the roads network (motor highways, state highroads, and modernised and local roads), along with the railroad network. A separate layout was allocated to the locality network, comprising the capital, municipalities, cities, communes and villages. For example, figure 1 displays the thematic layout with the localities and communication ways network. According to the structure of the hydro-meteorological data-collecting network, separate layouts were created, comprising the meteorological, precipitation and hydrometric measuring points.

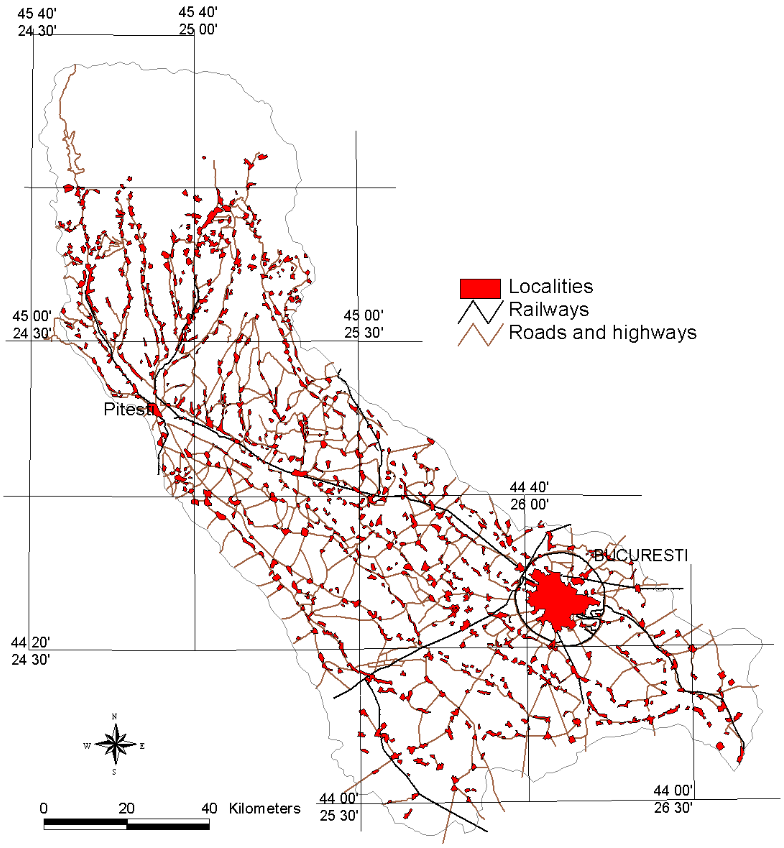


Figure 1. GIS thematic layout with localities and communication ways network in Arges basin

5. RETRIEVING FLOOD RELATED INFORMATION FROM SATELLITE DATA

After the geo-referencing in the stereographic map projection system, both visual and computer assisted photointerpretation, as well as automatic digital image processing methods have been applied in order to assess the extension of the area covered by water and the major land cover classes within the flooded zones. It was necessary to merge the photo-interpretation with the knowledge of the topography of the zones, thus excluding some incertain areas. LANDSAT-TM and SPOT-XS data have been used to perform a first 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.

Figures 2 (A and B) show an example of the flooded areas in the Arges basin determined from the 12th March 2000 NOAA 15 – AVHRR colour composite image and the location of the affected zones superimposed on the Digital Terrain Model (DTM).

One of the purpose of the study was the elaboration of a methodical tool that is capable of allowing the pasage from radiometric data to the information content, which offers an opportunity of interpreting the image with the consequent creation of relationships between the image structure an the elements of the corresponding real scene.

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.

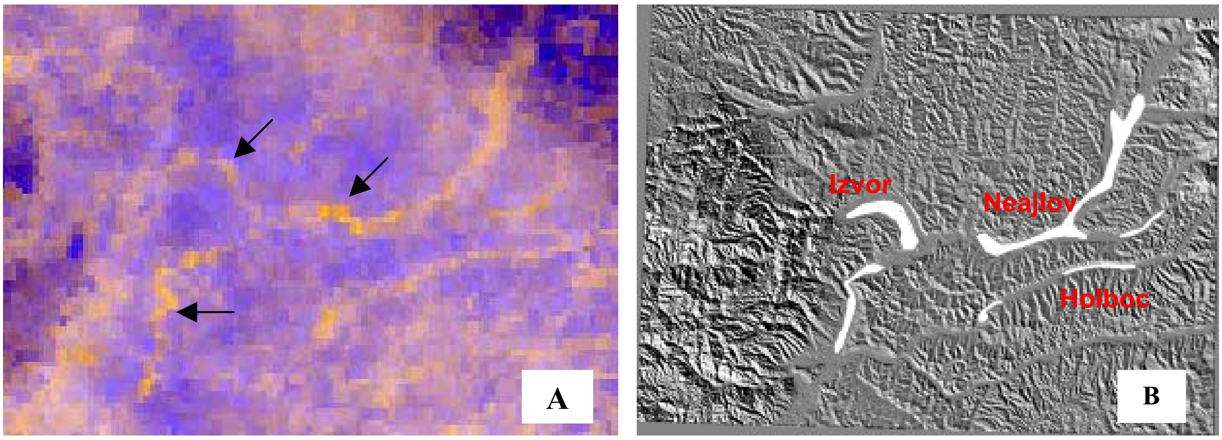


Figure 2. Flooded areas in the Arges basin observed on the 12th March 2000 NOAA 15 – AVHRR colour composite image (A) and the location of the affected zones superimposed on the DTM (B).

In case of SAR images the multitemporal techniques was considered to identify and highlight the flooded areas. This technique uses blanck 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 surfaceby 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 require the use of a reference image from the archive, showing the « normal » situation.

6. FLOODING RISK INDICES BASED ON PARAMETERS EXTRACTED FROM SATELLITE IMAGES

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). Of the numerous information deriving from analysing high spatial resolution satellite images (e.g. SPOT, LANDSAT), a series of criteria were determined from the radiometric information contained in image-data concerning the biophysical and anthropical parameters of basins.

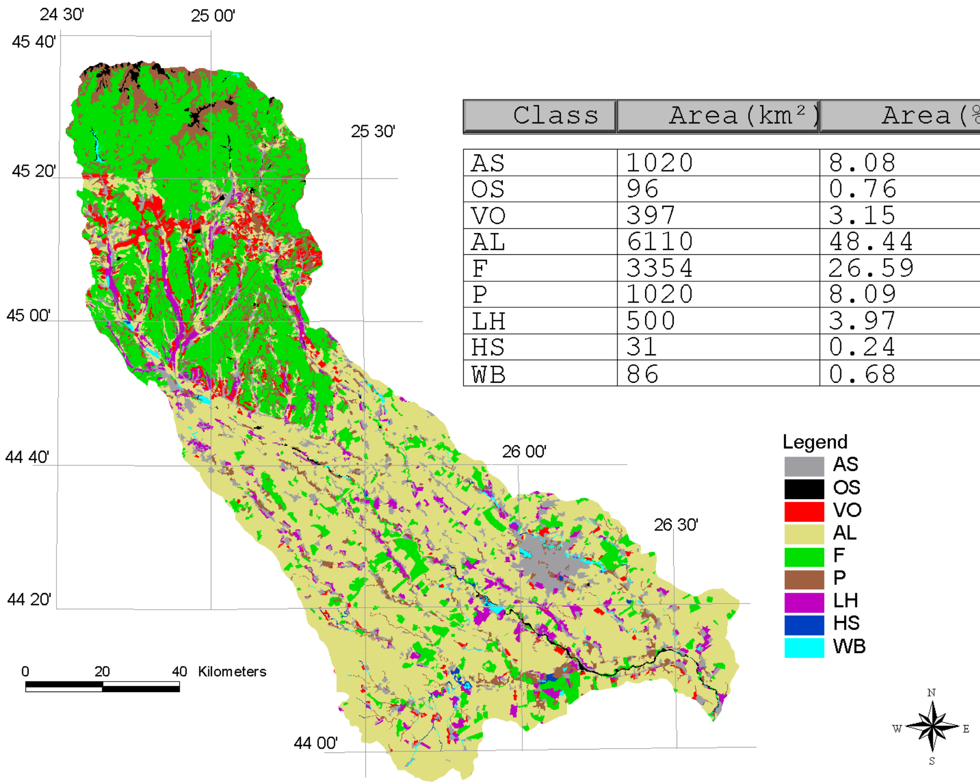
The morphological characteristics were extracted by image processing and from the DTM. The nature of this information, through the spatial and temporal coverage attributes may contribute to build complete databases suitable to allow simulations or scenarios. The following parameters were organised in hierarchical form by classes, in order to produce a synthetic and representative information:

- hydrographic network density – defined as the ratio between the length of the water flows over a surface and the respective surface (sub-basin). The water accumulation as a risk factor may be estimated function of the hierarchically categories for the network density: the denser the network, the faster the access speed to this network and thus the occurrence of high floods is more likely.
- water accumulation (usually associated to high flows) defined by the water amount captured by the hydrographic network; thus the larger the capturing area, the more important the water amount reaching the bed.
- size of potential flooded surfaces – the larger the surface, the higher the risk.
- soils impermeability degree – revealing the areas (sub-basin) with poorer vegetation coverage. These data are weighted through the slope and reported to basin surface.

These four parameters are weakly correlated: this explains through the complexity of the phenomenon and the parameters spatial extension used to define the hydrological risk.

Data resulted from LANDSAT-TM and SPOT-XS satellite images processing, by ERDAS Imagine Professional software, were used to compute the risk parameters. Also, the CORINE LAND COVER database obtained through computer assisted photointerpretation constituted a valuable source of information. Classification of land cover/land use was performed according to EUROSTAT catalogue in 44 classes.

Taking into account the necessity to obtain information concerning the parameters useful to quantify the flooding risk degree (impermeability degree, resilience in-soil water infiltration) there were performed regrouping of the land cover/use classes by 9 main types: 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). The obtained results for the Arges basin are presented in figure 3.



Class	Area (km²)	Area (%)
AS	1020	8.08
OS	96	0.76
VO	397	3.15
AL	6110	48.44
F	3354	26.59
P	1020	8.09
LH	500	3.97
HS	31	0.24
WB	86	0.68

Figure 3. Main land cover/land use classes of the Arges basin obtained from LANDSAT-TM data

These are useful information for the determination of the impermeability degree, function of the identified classes that may be assigned with impermeability coefficients, within a scale ranging from 0 to 1, as exemplified in the table 1. These coefficients allow determining the mean impermeability coefficient by sub-basin, weighted with their mean slopes.

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

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

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 the specific coefficients were assigned (table 2): artificial surfaces (AS), agricultural lands (AL), vineyards and orchards (VO), pastures and grass lands (P), lands belonging to households (LH).

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Class	AS	AL	VO	LH + P
Water absorption capacity (mm)	60	300	280	360

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

The allotted coefficients represent the precipitation amount, which a field is able to absorb. 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 basin function of their capacity to retain the water before the occurrence of the surface runoff.

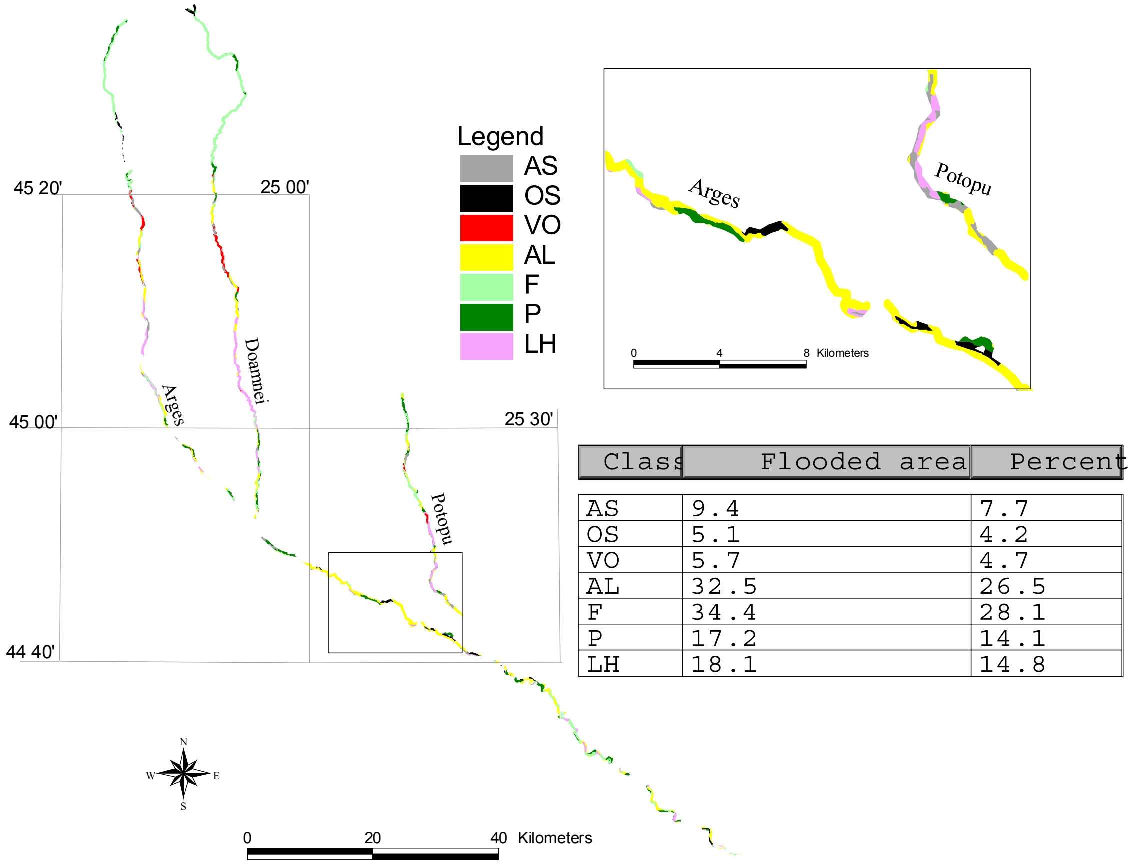
Another parameter connected to the land cover and use is the resilience to the in-soil water infiltration. The respective coefficients represent the considered area capacity to retain water at the beginning of the precipitation episode, before surface runoff start. Coefficients are expressed as precipitation amount (in mm) necessary for runoff start on slope, assuming water saturated soil. Actually this the water amount that the soil surface can retain, function of the various coverage, such vegetation, built areas, etc. the notion of flooding risk is in this case directly connected to the water runoff on slopes, known that the more intense the runoff, the higher the flooding risk.

In view to establish the resilience to in-soil water infiltration, the land cover and land use classes were regrouped by a number of four classes, to which the specific coefficients were assigned (table 3):

Class	AS	AL	VO	LH + P
Resilience to in-soil water infiltration (mm)	10-20	3-7	3-5	8-15

Table 3 Resilience to in-soil water infiltration values associated to the main landcover and landuse classes in the Arges basin:

On the basis of the mentioned risk parameters, as well as on the vulnerability degree expressed by the human presence (localities) seven classes were defined a qualitative scale (high – low degree). Given the water levels in the river, the terrain elevation, the flooding sensitivity information allows an accurate location of the zones affected by flooding and inventory of the damages. For example figure 4 reproduces the distribution of the land use categories reached by a 200 meters width buffering zone for flood simulation, along the rivers Arges, Doamnei and Potopu.



Class	Flooded area	Percent
AS	9.4	7.7
OS	5.1	4.2
VO	5.7	4.7
AL	32.5	26.5
F	34.4	28.1
P	17.2	14.1
LH	18.1	14.8

Figure 4. Inventory of land use categories in the area reached by flood for a 200 m width buffering zone along the rivers Arges, Doamnei and Potopu

7. 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 in a basin-test of Romania.
High satellite images proved to be a very important tool, through the synoptic vision of the territory and the geomorphological data they represent.
The analysis of the hydrological risk indices was associated to the topographic, morpho-hydrographic, physiographic and vulnerability characteristics within the Arges basin. The study encompassed both the risk degree levels associated with various parameters that condition and determine flooding, and the one, which takes into account the human

presence in sensitive areas. This approach implies establishing the vulnerability degree defined function of the costs of human and material nature which flooding may determine.

It was planned to design and build a database, which will help to elaborate the flooding hydrological risk indices. This database contains information associated to three main criteria: morphology-hydrology (hydrographic network, sub-basins, confluence order, density of hydrographic network and/or the drainage, the mean slopes by sub-basin, the mean slopes by river sections, land cover/land use (land impermeability, in-soil water absorption capacity, resilience to in-soil water infiltration) and vulnerability to flooding.

The database allows obtaining synthetic representations of the hydrologic risk for the Arges basin, 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.

Information extracted from satellite images of high spatial resolution represents useful data for the determination of certain parameters necessary to administrate flooding: hydrological network, water accumulation (usually associated to high discharges), size of potential flooded surfaces, land impermeability degree, etc.

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