Elaboration of products derived from geospatial data for flooding risk analysis in Romania

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Abstract In the last years, important floods occurred in Romania, engulfing wide areas and triggering loss of life and heavy damage. The modern management of geospatial data related to river flood risk relies on the functional facilities supplied by the GIS, combined with Earth Observation information and hydrological modelling, in view of establishing a methodology, which should further allow the elaboration of products useful for flooding risk analysis, such as: updated maps of land cover/land use, thematic maps with the extent of the flooded areas and the affected zones, maps of the hazard prone areas, risk maps for several probabilities of the maximum discharge occurrence, etc. These kinds of products started to contribute to preventive consideration of flooding in land development and special planning in the flood-prone areas, and for optimizing the distribution of flood-related geo-information to end-users.

Key words flood; flooding risk; geospatial data; satellite; Romania

INTRODUCTION

In recent years, important high floods occurred along most rivers in Romania, many recording historical discharges, engulfing wide areas and triggering heavy damage. The integrated remote sensing data started to play an important role in the creation of, or in updating, the existing GIS databases (Samarasinghe *et al.*, 2010). Earth Observation (EO) images have wide applications in flood analysis, e.g. in producing catchments maps, detecting water surface and soil moisture, detecting inundated areas, and assisting with remote flow measurement (Brivio *et al.*, 2002). Thus, satellite image processing is important for developing such products and using them in flood analysis and management.

The distribution of the graphic and cartographic products (derived using the GIS facilities and based on remote sensing data, maps and field surveys) to the interested authorities, media and public opinion is an important issue. These products contribute to preventive consideration of flooding in land development and special planning in the flood-prone areas, and for optimizing the distribution of flood-related geo-information to end-users.

CONTRIBUTION OF GEOSPATIAL INFORMATION FOR FLOODING RISK ANALYSIS

With an increasing impact of geo-hazards on society, the implementation of appropriate disaster reduction methods requires improved EO and coordinated hazards research activities. Satellite remote sensing can help to better estimate the hazard itself, to map the exposed elements, to estimate the vulnerability of the exposed elements, and finally to improve the quality of information that is made available to the decision makers.

Satellite remote sensing has proven an effective tool for producing flood maps and assessing flood damage, thanks to a variety of platforms and imaging sensors available, from radar to optical, from high to low geometric resolution (Gianinetto *et al.*, 2006). Within the framework of flood surveying, optical and radar satellite images can provide up-to-date geographical information. Integrated in a GIS environment, the flood-derived and landscape descriptive information is helpful during the characteristic phases:

(a) **Before flooding** The image enables the description of the land cover of the studied area under normal hydrological conditions;

(b) **During flooding** The image data set provides information on the inundated zones, flood map extent, and flood evolution;
(c) **After flooding** The satellite image points 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 geo-referenced information, obtained from optical and radar images, could be used in determination of certain parameters required in flood surveying and warning procedures, such as:

– the hydrographic network characteristics (length, width, density) and water accumulations;
– areal extent of flood plain inundation;
– areal extent (and water equivalent) of snow pack;
– size of the flood-prone area;
– land-cover/land-use features (to derive roughness, forested area, etc.);
– soil moisture condition;
– areal rainfall, both qualitative and quantitative indications.

The main advantages of using the EO data for flood monitoring and warning are related to the possibilities of directly observing spatially extensive variables that are otherwise only amenable to point sampling, to provide observations over inaccessible terrain, as well as with the determination of certain parameters useful to manage flooding (Wiesmann *et al*., 2001).

The limitations are due to the frequency of the satellite passing over the area of interest, to the resolution and nature of sensing equipment and to the sensitivity to obscuring clouds (for optical sensors).

FLOOD-RELATED GEO-INFORMATION PRODUCTS

The flood-related spatial information derived from satellite data and combined with the hydrological/hydraulic models outputs represent a valuable source of up-to-date geo-information for:

(a) **Prevention phase** Flood risk mapping from past events. The flood map extent derived from satellite data (overlaid with a map of a subset of a region or a town) enables improvement in the delimitation and risk assessment of flood risk zones. The identified at-risk areas are then combined with economic vulnerability information (e.g. to establish insurance fee criteria).
(b) **Crisis phase** Maps with the extent of the floods, flood extent evolution using multi-temporal satellite data. The flood monitoring from satellite data proved to provide the opportunity to quickly and precisely overview flooded areas. Through multi-temporal analyses, the duration of flooding can be determined.
(c) **Post-crisis phases** Flood extent mapping and damage assessment. In the aftermath of a crisis, damage quantification could be made easier by jointly analysing the spatial trends of flood duration, the land use within the affected area and, eventually, the company contracts with their customers. Satellite-derived products act as support of damage assessment. This can be conducted for example using flood extent overlaid with a city map in high resolution.

The evaluation of flooded areas enables improvements for planning, as e.g. the declaration of risk areas. Large area evaluations allow the verifying and improving of model calculations. Additional information, such as land use (industrial areas, settlements, agriculture, forest) are intersected with flooded areas, allowing the detection of affected areas, which have to be protected against flood events in future.

The flood extent evolution using multi-temporal satellite data provide the opportunity to quickly and precisely overview flooded areas, as well as the evaluation of spatial and temporal dynamic of the flood.

The satellite data for the flooded areas (SPOT 4/5, LANDSAT 7 ETM+, DMC/FORMOSAT, RADARSAT and ERS) have been obtained in quasi real time from the International Charter on Space and Major Disaster and in the framework of the SAFER (Service Applications For Emergency Response) FP7 project, considered as the pre-operational European Emergency

Response Core Service. The MODIS Land Rapid Response System (developed to provide rapid access to MODIS data globally, with initial emphasis on 250-m colour composite imagery) has been extensively used for flood extent mapping due to free and easy access to the satellite data.

In order to update the land cover information and to accurately locate the geo-referenced points in the flood-affected areas, high spatial resolution satellite images have been used (TERRA/ASTER, LANDSAT 7 ETM+, SPOT 5, FORMOSAT, etc.).

Different types of satellite-derived products have been produced and disseminated daily to the decision makers via the web system: flood extent maps, maps of the flooded areas embedded in reference satellite image as background, flooded areas merged in a GIS environment, dynamics of the flooded areas, 3-D visualizations, animations, quantitative estimations of the affected areas, updated maps of the land cover/land use, flooding risk maps, and snow cover maps.

The geospatial database

The geospatial database structure is represented by the spatial geo-referential information ensemble (satellite images, thematic maps, series of the meteorological and hydrological parameters and other exogenous data) and is structured as a set of file-distributed quantitative and qualitative data focused on the relational structure between the info-layers.

The database contains different thematic plans, organized info-layers: land topography (organized in DEM), hydrographic network, dikes and canal network, communication ways network (roads, railways), localities, meteorological stations network, raingauge network, hydrometric stations network, sub-basin and basin limits, and land cover/land use. The geospatial database is connected with the classical hydrological database so as to obtain synthetic representations of the hydrological risk using separate or combined parameters.

The construction of this geospatial database was based, mainly on classical mapping documents, particularly represented by maps and topographic plans. Due to the fact that, in most cases, the information on the maps is out of date, it is proposed to update it on the basis of the recent satellite images (e.g. the hydrographic network, land cover/land use) or by field measurements (e.g. dikes and canal network).

The database contains the following info-layers: sub-basin and basin limits; land topography (90-m DEM); hydrographic network, dikes and canal network; communication ways network (roads, railways); localities; meteorological station network, raingauge network, hydrometric station network; land cover/land use, updated from satellite images.

Using the geospatial database, several outputs of the VIDRA and HRM forecasting models can be superimposed on the GIS environment in order to elaborate the flooding hazard and risk maps. Figure 1 shows the schema of the integration of hydrological/hydraulic model outputs with the GIS info-layers.

Specific methods for satellite-based flood extent mapping

The most efficient method for water identification and mapping depends on the type of available satellite information, in the optical or radar spectral domain, as well as on the spatial resolution

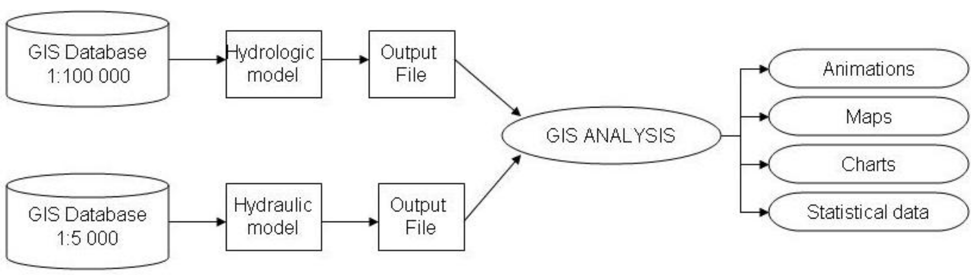

Fig. 1 Integration of hydrological/hydraulic models outputs with the GIS info-layers.

this information could provide. For operational purposes, in the case of extreme flood an efficient method means a simpler and fast one.

The method, based on multi-temporal image inter-comparisons, determines the land-cover change detection, including the flooded areas. For the flood mapping retrieval, the relative radiometric normalization techniques have been used; these procedures are aimed towards reducing atmospheric and other variation among multiple images by adjusting the radiometric properties of the target (slave) images to match a master (reference) image (Chen *et al*., 2005).

Several relative normalization techniques have been tested, including simple regression, pseudo-invariant features and land cover classification.

After performing the radiometric normalization of the slave image onto the master image, normalized reflectance has been used for flood mapping purposes, with the final aim of assessing the influence of the radiometric normalization process for that specific application. The flood maps were derived using a simple threshold on the normalized near-infrared reflectance differences. The use of radiometric normalization increased the mapping accuracy compared with un-normalized data, strengthening the acknowledgement of radiometric normalization influence in change detection analysis.

Spatial geo-information preparation for rapid access

To make all the work easily available to the contributurs and end-users, a detailed specification package has been developed. In this respect, every piece of information uses the same file format (ESRI shapefile for vector data; ESRI grids for digital elevation model; ERDAS .img for maps and satellite images) and the same geographic system of coordinates: UTM Zone 34/WGS 84.

A Satellite Image Database (SID), to gather information about satellite scenes available, as well as of the derived products, has been built in MySQL and is available online on the main server being updated as new satellite images are acquired. The purpose of the SID is to gather information about the raw satellite scenes available as well as of the derived products, and make it available in a simple format. This information is useful to test the processing and analysis algorithms for the water detection, mapping and analysis of flooding. Each record of the database describes the characteristics of satellite image: platform, sensor, date and time of data acquisition, duration of pass, spectral band, coordinates of the area covered, projection, calibration, size, bits/pixel, image file format, physical location (machine, directory), origin of data, type (raw/processed), type of processing applied, algorithm used, quick-look available, cloudiness, etc.

Spatial geo-information dissemination over internet

A dedicated online system, based on satellite data and geospatial technology, for flood related geo-spatial information management has been design and implemented in the Romanian Meteorological Administration (Stancalie *et al*., 2009).

The GIS and satellite-derived data configured for web use, are based on:

– a spatial data server that can efficiently communicate with a web server and is able of sending and receiving requests for different types of data from a web browser environment;
– a mapping file format that can be embedded into a web page;
– a web-based application in which maps can be viewed and queried by an end-user/client via a web browser.

The key components of the sub-system (Fig. 2) are:

– **Core server** is the core component of the system since it handles the interactions between the various modules, the end-user management, the display and manipulation of data. This core server includes a web server that manages the information to be distributed over the web on requests from end users and which is able to communicate with the database server and the map server;
– **GIS database** is the component that handles all databases of the system; it stores the data and extracts data as needed;

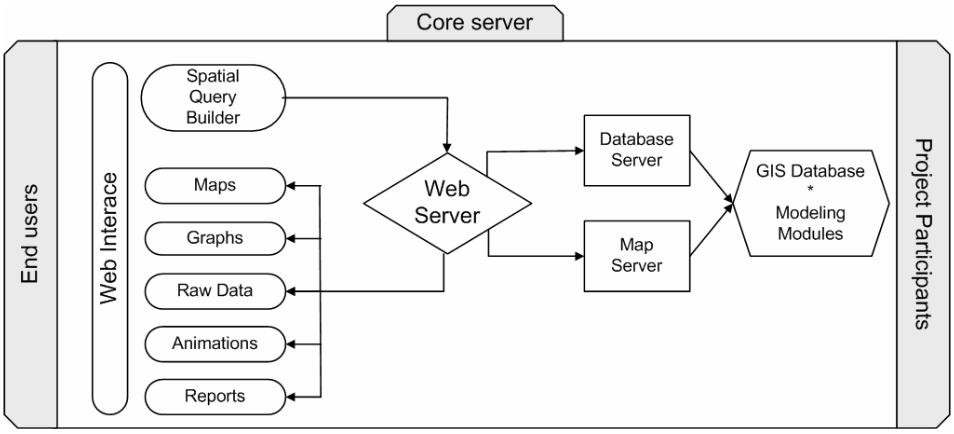

Fig. 2 The key components of the online system for spatial geo-information dissemination.

– **Modelling module** integrates the various hydrological and hydraulic models into the system; it applies the model on a defined data set, monitors the progress and the status of the processes (needed since flood models can sometimes run for several hours) and sends the results to the rest of the system.

The online system has been developed following a distributed architecture, and end-users can access the system using a simple web browser to display, query, analyse and retrieve information. One of the most important functions of this online system involves distribution of the flood related geo-information. The system considers three user levels: project participants, strategic end-users, media and other people.

The internet web-based network represents a powerful and effective communication method. Publishing the data on the web (web mapping) using this approach would not change the existing data workflow – how the data are created, maintained, and used by desktop applications. This means that the map server dynamically generates maps from the files stored in a certain folder every time a user sends a request.

The web-based application has been developed using standard technologies such as: HTML, XML, JavaScript, PHP, SVG, COM. The web-based application supports the Open Geospatial Consortium (OGC) and the Open Web Services specifications.

The web mapping interface has the following outline:

(a) **Basic display** represents the focal point of the system, which is placed where the cartographic content is loaded. The size of the display may be fixed or the user can change that according to his local screen settings. Since only a small part of the underlying geospatial data set is displayed, users should be able to move to their area of interest by means of panning and zooming. Both the Zoom and Pan tools may be implemented in the interface in a multitude of ways. For example, the tools can act interactively (the user defines on the map the area which will be affected by zoom or pan) or static (e.g. for zoom, the user presses the zoom in/out button and the view is enlarged/reduced to a predefined level).

(b) **Navigation and orientation** tools involve the keys to the web mapping. At any time, users are able to know where the view is located and what the symbols mean by means of overview maps, scale indicators and legends.

(c) **Querying data** during navigation, users can access the geospatial database by querying the data. This requires tools to construct more elaborate questions and search requests. The queries can be constructed by form input, or can be map-based queries by selecting objects or defining areas of interest.

(d) **Multi-scale** combining different geospatial data sets represents is a specific operation to obtain the raw data for web mapping. The publishing application can deal with multi-scale data because usually these sets will have different scales and levels of generalization.

(e) **Multiple dynamically linked views** These tools represent a combination of multimedia and brushing techniques which enable users to view and interact with the geospatial data in different windows. These views do not necessarily contain maps but video, sound, text, etc. can all be included.

Users can access different geospatial products through the web browser and perform queries, and retrieve different products useful for flood management, such as satellite-derived maps with the flooded areas, land-cover/land-use maps, flood hazard maps, for several probabilities of the maximum discharge occurrence, flow related charts, etc.

CONCLUSIONS

In recent years, the products derived from geospatial data started to play an important role for flooding risk analysis. In this respect the satellite images have wide applications in flood analysis, in such tasks as producing catchments maps, detecting water surface and soil moisture, detecting inundated areas, and assisting with remote flow measurement.

The distribution of the graphic and cartographic products (derived using the GIS facilities and based on remote sensing data, maps and field surveys) to the interested authorities, media and the general public is an important issue. These products contribute to preventive consideration of flooding in land development and special planning in flood-prone areas, and for optimizing the distribution of flood-related geo-information to end-users.

For Romania, such a system will strengthen the collaborative approaches between the existing expert institutions/groups in the domain of geo-information applications for disaster management and will contribute to the availability of critical information for decision-makers and other end-users.

Experience gained in the current activities showed that user organizations, although not experienced in using or taking benefit of the informational content provided by EO data, are starting to be more effective in using EO-derived information products.

To better answer the user needs, a clear distinction should be made between the different roles the user organizations are currently playing. When talking about flood disaster management, it is important to know if a user organization is involved in pre-disaster, response or post-disaster activities.

The higher resolution, timely and updated data still remains a strong requirement coming from the user community.

Continuous interaction with the user organizations is very important for setting up and developing effective services involving the use of EO data in flood disaster management. In the near future a great concern is dealing with the use of the new satellite facilities and performances of the data received from present and near future sensors in order to improve the capabilities of operational evaluation, mapping and analysis of flood-related phenomena.

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