EVALUATION AND MONITORING OF SNOWCOVER WATER RESOURCES IN CARPATHIAN BASINS USING GEOGRAPHIC INFORMATION AND SATELLITE DATA

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KEY WORDS: Snow Ice, Satellite, Monitoring, Integration, GIS, DEM

ABSTRACT:

The paper describes the working methods developed in the Remote Sensing Lab of the National Institute of Meteorology and Hydrology in Bucharest and the obtained results for: basin snowcover areal extent and snowline elevation determination, new snowfalls identification, melting zones discrimination, snowpack water volume determination, snowcover depletion curves, etc.
The method for evaluation the water resources stored in the snowpack is based on the use of data from three investigation levels: satellite, air and ground. This approach is required by:
- the complex physiographical peculiarities of the Carpathian watershed;
- the necessity of determining both the extent of the snowcover and its condition;
- the instability in time, during the winter-spring season, of the maximum stored amount, and the snowmelt process beginning which requires a continuous surveillance of the snowcover;
- the need to correlate remotely sensed data with the ground truth.

A complex related geo-referenced database, consisting of high and medium resolution satellite data (NOAA-AVHRR, TERRA-MODIS, LANDSAT-TM, SPOT-XS), terrain information derived from Digital Elevation Models (DEM) and other exogenous data (maps and ground measurements) was designed and implemented on PC-based computing systems. The GIS developed for the snowcover water resources management includes information referring to the topography, land vegetation cover, land use, soil type, hydro-meteorological parameters, that could be used as separate layers or interconnected in order to extract the necessary information for a correct and accurate estimation of the snowpack conditions and snowcover water resources during the winter-spring period.

1. INTRODUCTION

The surveillance and the management of the water resources in Romania represent an issue of national importance considering the fact that the natural potential of the water courses is rather reduced, altered by water consuming users and by those which redistribute the flow in time. Although the number of the watercourses is considerable, Romania is situated among the European countries with relatively poor water resources; the multi-annual mean runoff for the Romanian territory reaches the limit of the hydrological drought, over extensive areas in the east and southeast.

Water resources management requires a permanent surveillance in space and time of the snow cover, one important natural water resource. This activity requires a great number of observations points and stations of measurement and processing.

The remote sensing technologies have known an unprecedented development in the latest years; there are many operational systems with sensitive sensors in many areas of the electromagnetic spectrum, from visible to microwave, with spatial and temporal resolutions extremely notable. Now, the remote sensing represents a viable alternative, being able to supply observations and global measurement at the level of a hydrological basin or for larger areas. The remote sensing techniques offer important advantages such as:
- areal measurements;
- gathering and unitary data storage;
- good spatial and temporal resolution;
- data available in numerical format;
- availability of data in less accessible areas;
- the acquisition systems do not interfere with the process and observed phenomena.

Among the major difficulties connected with the obtaining and use of the remote sensing data, the atmospheric conditions are to be noticed for the optical sensors and those linked with the calibration of the information by means of field data in hydrological terms.

Remote sensing data play a rapidly increasing role in the field of snow hydrology. Although only very few remotely sensed data can be directly applied in this field, such information is of great value since many hydrological relevant data can be derived from remote sensing information. One of great advantages of remote sensing data in hydrology consists in the areal information instead of the usual point data. This information is usually digitized in form of picture elements, the scale of which depends on the sensors, which are used. Large quantities of raster data are collected with the aid of various platforms and sensors. These large data amounts require well organized data banks as well as user friendly data processing hardware and software.

It was noticed that remote sensing data would be particularly valuable for regions with complex terrain, when the snow parameters, such as snow-water equivalent, may vary significantly over small areas. Such data need to be compared with ground station data - "ground truth" - in order to provide calibrated data sets.

The cost of collecting and using remotely sensed data could be very high, so the use of this data should be carefully evaluated. The cost of collecting adequate ground-station data could be even higher, so the trade-offs between the two data types need to be examined.

2. THE HYDROLOGICAL REMOTE SENSING SYSTEM

A remote sensing system for the surveillance and management of water resources can be defined as the result of the co-ordination use of the knowledge regarding the modern sensors, suitable for water detection in its various states, the data processing equipment, the theory of information and decision-making, the methodology of data processing as well as the specific communication systems. The structure of such a system consists of:

- a central unit that represents the proper storing, processing and analysis data systems;
- a network of ground sampling stations in which measurements of the hydro-meteorological parameters are performed and where a series of special measurement programs are carried on (radiative characteristics of the snow in different conditions, atmospheric parameters, etc.);
- communication channels with the reception satellite or with the units that can supply such data, with the meteorological radar network, with the specialized units in order to carry out the aerial flights with the network of ground measurement stations and with the users.

On its turn, the central unit behaves like a system composed by subsystems. In this way, the main data inputs are received through the telecommunication subsystem.

The achievement and operation of the open system implies:

- to ensure the data from high and mean resolution satellites, from the radar network, as well as to ensure some repeated flights for the basins of interest.
- to obtain the storing and processing technology of the image data, and the conventional data transmitted in slow and rapid flux;
- to create the data bank, to organize a GIS dedicated to the surveillance and valuation of the water resources in the national territory.
- to elaborate hydrological synthesis and prediction models that accept the data resulted from the processing of remote sensing information.

3. GIS APPLICATIONS IN SNOW HYDROLOGY

For many hydrological purposes remote sensing data alone are not sufficient; they have to be merged with data from other sources. This is a field where GIS's are extreme value. The technique of merged information from different sources into one system has to be carried out with great care. It is necessary to use the same coordinate system, to work on the basis of equal pixel size.

A combined remote sensing data base consisting of satellite, aircraft data and digital terrain information derived from DEM proved to be well suited in establish relationships between a hydrological state vector and measurable hydrological interdependent features of a basin (vegetation types and density, elevation slope and aspect of the relief).

GIS represent highly suitable opportunities for efficient handling of large quantities of data. They allow the necessary merging of remote sensing data with DEM as well as with other hydro-meteorological data.

The GIS developed in the National Institute of Meteorology and Hydrology for the snow cover water resources evaluation and monitoring, in the Carpathian watersheds includes many geocoded information organized in a complex related data base. Data referring to the topography, organized in DEM (figure 1), obtained from Shuttle Radar Topography Mission (SRTM), land vegetal cover (figure 2), land use, soil types, hydro-meteorological network, hydro-meteorological parameters, may be used as separate layers or interconnected in order to extract useful information for a correct and accurate estimation of snow pack conditions and snow water resources, during the winter-spring period.

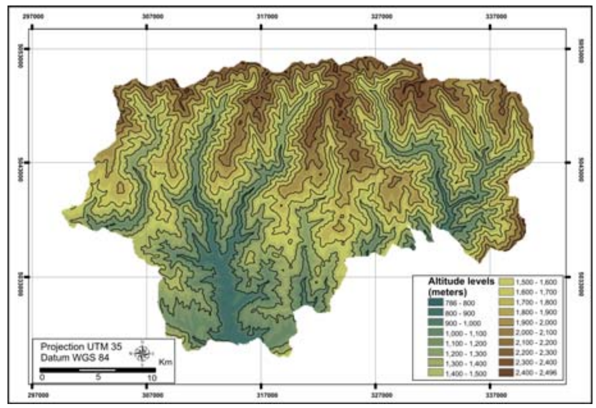

Figure 1. Altitude levels derived from 90 m cell SRTM DEM for Arges basin

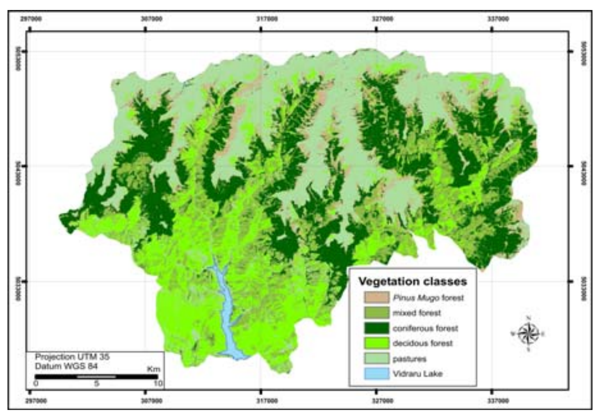

Figure 2. Land cover derived from LANDSAT 7 ETM+ (04.07.2002)

The possibility of merging satellite imagery in the GIS allows the use of updating spatial information for land cover, land use and also for the evaluation of snow cover characteristics.

The DEM is very important for the evaluation of the morphometric parameters of the watershed: the slope and aspect, the sun exposition of the slopes, the slope limit variation etc.

The intersection of the DEM with the vegetation cover layer allows for example the determination of forest areas distributed on altitudinal levels. By merging the map of the slope aspect with the vegetation cover layer, a representation of the vegetation distribution, function of the aspect of the slopes over the basins may be obtained.

The dynamics of slope limit variations may be derived by applying the gradient function (horizontal or vertical) on the DEM.

The merging of LANDSAT-TM or SPOT satellite multispectral imagery with the DEM is useful for updating the vegetal cover and for the evaluation of some parameters of the snow accumulation or snow melting processes: retention coefficient, infiltration coefficient, waterflow coefficient, etc.

4. SATELLITE DATA FOR HYDROLOGICAL MODEL PARAMETER ESTIMATION

A more complex application of remote sensing data in hydrology consists in the use of such data either for the estimation of parameters of hydrological models or as input into such models. For both purposes the application of GIS and remote sensing improves the efficiency of such procedures significantly.

The condition of the land surface (land cover, land use, vegetation status etc.) influences hydrological process like precipitation interception, infiltration and water runoff. In many cases such information is derived from digitized maps which are stored in GIS. This conventional technique has several disadvantages because maps are often outdated and low accuracy. These problems may be overcome by land cover/use classification carried out with the aid of satellite imagery.

The snowmelt-runoff process is influenced by the vegetation status. There are various indicators for this vegetation status, like the "Normalized Difference Vegetation Index" (NDVI), determined with the visible and near-IR satellite channels (figure 3).

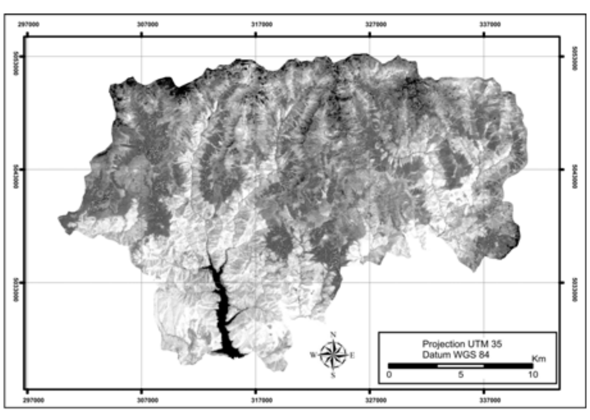

Figure 3. NDVI map for Arges basin obtained from LANDSAT 7 ETM+ (04.07.2002)

Another type of information, which is frequently used in hydrological modeling, is the subdivision of a drainage basin into "Hydrological Similar Units" (HSU), which behave in the same way. The determination of the HSU's requires data on soil type, land use, on elevation, slope and aspect. So it is possible to obtained the areas of equal hydrological behavior due to their equal land use, slope and soil type. This is valuable information for the water flow modeling in the snowmelt period.

5. REMOTE SENSING MONITORING OF SNOWPACK DYNAMICS IN VIEW OF ESTIMATING THE SNOW COVER WATER RESOURCES

The efficient and rational management of water resources in a drainage basin involves the knowledge of snowpack conditions evolutions and the snowcover phases of the snowmelt season.
In the National Institute of Meteorology and Hydrology in Bucharest technical means and working methods were developed for operational applications in the following field of the snow hydrology: watershed snowcover areal extent and snowline elevation determination, new snowfalls identification, snowpack depth estimation, ablations monitoring and melting zones discrimination.

The method for evaluation the water resources stored in the snowpack (Stancalie, 1991) is based on the use of data from three investigation levels: satellite, air and ground. This use is required by:
- the complex physiographical peculiarities of the Carpathian watershed and their relatively restricted area which calls for the use of large scale imageries.
- the necessity of determining both the extent of the snow cover and its condition which calls for the use of multispectral image-data;
- the instability in time, during the winter-spring season, of the maximum stored amount,
and the snowmelt process beginning which requires a continuous surveillance of the snow cover , which imposes the repetitive air and satellite imageries and data from the hydro-meteorological network in rapid flux;
- the need to correlate remotely sensed data with the ground truth.

Due to the variation in terms of altitude of the physiographical and meteorological factors conditioning the snow cover, the extension of watersheds over a relatively great altitude range (600-2500 m) have led to:
- the division of each watershed under consideration into altitude levels of 100-200 m;
- the estimation of the areas under the main types of vegetation cover at each altitude step.
The need to obtain ground truth data has required the selection and delimitation of some sampling areas that should cover the most important types of land cover, classified according to their capacity for snow storing.

The determination of the snow cover extent and the monitoring of snow over the basin being investigated, at various moments in the winter-spring season used:
- a direct method for singling out the areal with snow from the imageries by means of the facilities provided by the processing systems;
- an indirect method of converting the average snow line altitude in the area by means of the hypsometric curve of the watershed.

For the purpose of obtaining the information concerning the area of the snow cover one has employed the binarization of the ratio between the signals in the NIR and visible on the basis of a threshold obtain by means of data from test areas. The method allows of minimizing the effect of shades.

The surveillance of the dynamics of the snow cover is done by the depletion curves of the snow-covered areals. These curves vary function of the type of the watershed and climatic conditions, their shape being dependent upon the physiographical characteristics and the altitudinal range. The latter can enhances the accumulation differences and those noticed in the rates of melting in various areas of the basin.

With most applications one has employed the modified depletion curves where the area covered with snow is expressed in degree-days accumulated, starting from a balanced temperature. The advantages one may derive from using these curves reside in that they can be extrapolated on the basis of the maximum forecasted temperature values.

For the Carpathian basins four principal types of snow cover depletion curves where established (figure 4):
- the A type corresponds to increasing snowmelt depletion rate;
- the B type is characteristic to a slower melting rate in some sectors of the basins, mainly because of the snow accumulation arised during the melting season;
- the C type characterizes a faster melting during the first period, followed by more reduced accumulations in some areas;
- the D type is representative for a basin which can be divided in two areas of different characteristics: one area within reduced accumulation and/or faster melting rate and the other with a more important accumulation and/or reduced melting rate.

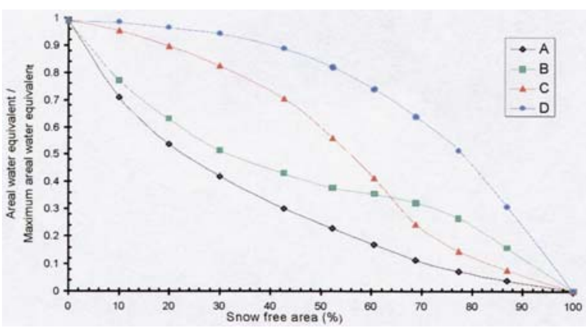

Figure 4. Areal snowcover depletion curves characteristics for the Carpathian basins

The water amount in the snow cover is calculated from data concerning the depth and density of snow as well as the area it covers.

The determination of the water content of the snow in the mountain watersheds is affected by errors occurring during the data acquisition and processing stages.

The accuracy in determining the areal data obtained from images depends upon:
- the spatial resolution of the sensors and geometric correction level ;
- tonal contrast of images;
- existing interference objects (clouds, shadows, relief);
- temporal frequency of available images.

When snow cover areas are determines indirectly by snow cover depletion curves extrapolation, based on forecasted temperatures, the accuracy also depends on the errors related with the temperature forecasting.

Snow physical parameters vary with elevation and land vegetal cover and the accuracy of their measurement values involves the representativity of ground stations network.

The accuracy in estimating the water resources in the snow by the presented method is in the range 5 - 15 %.

6. DETECTING SNOWPACK CONDITION FROM VISIBLE NEAR-IR SATELLITE CHANNELS

Use of near-IR data in conjunction with reflected visible radiation allows detection of early melting stages of snow and ice. Under normal conditions snow and ice are highly reflective (80-90%) in both the visible and near-IR channels. But under melting conditions near-IR radiation is absorbed, whereas visible radiation is strongly reflected.

Comparison of simultaneous visible and near-IR imageries from LANDSAT-TM or NOAA-AVHRR satellite provides a method for monitoring snow melting that can be applied to runoff prediction.

Where deeper accumulations persist the snow albedo apparently remains relatively high during the melting period. The depth of the snow is an important factor which controls the albedo of plain and hill regions, whereas the metamorphic processes may play a secondary role. The study of spatial variability of snow albedo may be achieved utilizing airborne and satellite imageries.

7. SNOWMELT RUNOFF MODELLING AND FORECAST BASED ON REMOTE SENSING INFORMATION

The advent of remote sensing data caused some confusion among the hydrologists since the information obtained by remotely sensed data could not be used directly in many of the existing models (Schultz & Barrett, 1989). The reason for this was the fact that:
- the input data consist in electromagnetic information instead of hydro-meteorological data;
- the resolution in time and space is sometimes higher or lower than necessary due to the available sensors.

We have to clearly distinguish between the estimation of model parameters on the basis of remote sensing data and the estimation of model input with the aid of the remote sensing information.

If we deal with physically based distributed system hydrological models, many model parameters characteristics depend on the parameters of the hydrological systems such the catchment/river characteristics. Some of these characteristics may be derived from the image-data (vegetal cover, land use, morphometric parameters).

Also model input data can be estimated from the remote sensing data. For the computation of snowmelt, the snow cover area, the reflected radiation (albedo) and temperatures are relevant

parameters that could be derived from remote sensing information.
There has to be a correspondence between the resolution in space of the distributed system type model and the resolution of the input data.

Runoff streaming from snowmelt can be estimated with snowmelt runoff model (SRM). The SRM (Martinec at all, 1994) model can simulate and forecast daily stream flow in mountain basins where snowmelt is majored component of the water balance. The required model input consists of periodic snow cover areas estimated from satellite (LANDSAT-TM, SPOT, NOAA-AVHRR) or from air photos, daily temperature and precipitation.
The snow cover data are used to construct the snow cover depletion curves for different zones in the basin.

Certain model parameters relevant for snowmelt runoff can be estimated on the basis of the land use/land cover classification and vegetation index, derived from multispectral data.

The forecasting, of the watershed flow generated by liquid precipitation and snowmelt is expressed by a general relation of the following form:

$$V_{snow} + V_{pp}) \cdot \alpha = V_T \qquad (1)$$

where: V_{snow} - water volume stored in the snowpack ;
V_{pp}- water volume generated by liquid precipitation;
α - water flow coefficient;
V_T - total water volume measured on the river at the watershed outlet.
The error that determines the accuracy of the total flow in a watershed (ε_{VT}) is done by:

$$\varepsilon_{VT} = \varepsilon_\alpha + (\varepsilon_{Vsnow} V_{snow} + \varepsilon_{Vpp} V_{pp}) / (V_{snow} + V_{pp}) \qquad (2)$$

The averaged accuracy of the water volume stored in the snowpack is about 90 - 93 %. The averaged accuracy of the water flow coefficient and of the water volume generated by the liquid precipitations may be considered in the range 70 - 80% (taking into account the averaged accuracy of the meteorological forecasting).

The improvement of reservoir exploitation depends on the accuracy of the hydro-meteorological forecastings and of the decision efficiency that can be taken on that basis.

The study of the relation between the accuracy, decision efficiency and anticipation forecasting time is useful to establish the optimal zone of the forecasting methods. The spatial forecastings based on remotely sensed information are located near the central zone of the optimization curve. So, it is highly recommended for the improvement of the reservoir exploitation, the use of spatial forecasting method.

CONCLUSIONS

Snow melting and the occurrence of the flow resulted from the snow mass accumulated during winter-spring period is one of the important phases of the hydrological cycle within the basins of the Carpathian rivers.

Remote sensing data play a rapidly increasing role in the field of snow hydrology. One of the great advantages of remote sensing data in hydrology consists in the area information instead of the usual point data. The cost of collecting and using remotely sensed data could be very high, so the use of this data should be carefully evaluated. The cost of collecting adequate ground-station data could be even higher, so the trade-offs between the two data types need to be examined.

The possibility of merging satellite imagery in the GIS allows the use of updating spatial information for land cover, land use and also for the evaluation of the snow cover characteristics.

A combined remote sensing data base consisting of satellite, aircraft data and digital terrain information derived from DEM proved to be well suited in determining snowcover area extend, snowline, melting zones and water volume stored in the snowpack on different Carpathian basins of Romania.

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