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THE INDIRECT EVALUATION OF THE SOIL WATER RESERVES WITH THE AID OF ARGIS. AN APPLICATION TO THE NADĂŞULUI BASIN (APUSENI MOUNTAINS, ROMANIA)

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Abstract: Using numerical models and GIS functions, have been drawn maps with soil characteristics, land use, terrain morphography and morphometry (on the basis of the digital elevation model) for Nadăş basin. Using then the rainfall regime data, soil humidity was computed and interpolated for different periods of the year.

Key words: *soil water reserves, GIS*

Purpose

The hereby paper aims at determining the soil characteristics of the soil form the Nadăşului Basin, with the aid of some numerical models combined with a series of specific GIS functions. The soil humidity generally refers to the water quantity contained by a soil sample at a certain time, whether if we talk about water from different natural sources (liquid precipitations, the melting of the snow layer, phreatic water etc.) or artificial water (from irrigations or possible accidents in the management of the water basins).

Such water quantities can be expressed in volumes (m^3) or, most often as water layers (mm); they depend on the quantity of precipitations (liquid or solid) entered in the basin, on the duration of the rain, on the intensity, and also on some physical characteristics of the soil entities (permeability, structure, texture, retention, infiltration speed etc.) or on characteristics correlated to the landuse and the degree of forestation. The role of the morphometric features (altitude, slope, orientation, etc) of the land must not be neglected either, as they are factors affecting the distribution of precipitations (the altitude), the preservation of the snow cover (the orientation), the distribution of flow, the accumulation time, the infiltration speed etc. (the slope).

The main objectives of the study can be summarized under the following aspects:

- The presentation of certain indirect methods in estimating the degree of moistening of the soil within a certain area, based on some physical – geographical parameters;
- The analysis of the parameters which influence the soil humidity with the use of GIS, with a focus on the Nadăşului Basin;

➢ The application of the methods and the materialization of some results;

Indirect methods of estimating the water reserves from the soil

The water reserves from the soil at a certain time can be estimated successfully by using some models which consider an array of parameters, indexes related to the morphologic and morphometric characteristics of the terrain, the land use and the pluviometric properties. The methods used in this paper are: **API** (**A**ntecedent **P**recipitation **I**ndex) and the water balance method**.**

*The Antecedent **P**recipitation **I**ndex Method*

API was a method first used by Kohler and Linsley (1949). It allows the estimation of soil humidity by considering the previous pluviometric characteristics of the analyzed land. Its mathematical expression is presented bellow:

$$\mathbf{I_t = K_t \bullet I_{t-1} + P_t} \qquad (1)$$

where:

- I_t – API from day „t" (mm);
- I_{t-1} – API from the previous day (mm);
- K_t – a regression parameter (reduction);

Another API relation is:

$$\mathbf{API_i = API_0 \bullet k^i} \quad \text{or} \quad \mathbf{API_i = API_0 \bullet e^{-\alpha^I}} \qquad (2)$$

where:

- i – the number of days between API_i and the initial index (API_0);
- k – a parameter related to the physical characteristics of the basin; it is sub unitary;
- $\alpha = - \ln k$

If i=1, then $API_i = API_0 \bullet k$

The water balance method

Another method for characterizing the moisture state of the soil cover is proposed by Simota Maria and Mic Rodica (1993). It considers the following parameters: the flow coefficient (α), dependent on the sum of previous precipitations; the *evapotranspiration* (ET); the daily mean precipitations in the basin (Pi).

$$U = (1-\alpha)\cdot(\sum_{i=1}^{10} Pi) - N \cdot E \qquad (3)$$

where: N – the number of days without precipitation.

The flow coefficient (α) can be determined based on the sum of previous precipitation (Table no.1).

Table 1. *The expression of the flow coefficient α* (after Rodica Mic and Corbuş C.)

$\sum P_i$ (mm)	< 10	10–30	30–50	50–80	80–100	100–140	140–180	>180
1-α	0,7	0,6	0,5	0,4	0,35	0,3	0,25	0,25

In our analysis the determination of the flow coefficient was achieved based on the slope, the land use, the soil texture. In this respect we used the indexes used by Frevert (Table no. 2).

Table 2. *The expression of the mean values of the flow coefficients* (after Frevert)

Use	**Slope (%)**	**Soil Texture**		
		Mild	Mean	Heavy
Forrest	0 – 5 5 – 10 10 – 30	0,10 0,25 0,30	0,30 0,35 0,40	0,40 0,50 0,60
Agricultural crops	0 – 5 5 – 10 10 – 30	0,30 0,40 0,50	0,50 0,60 0,70	0,60 0,70 0,80

The quantity of evaporated water was estimated based on the month for which the calculation of the soil humidity was computed. (Table no.3).

Table 3. *The expression of evapotranspiration based on the year period* (after Rodica Mic and Corbuş C.)

Month	April	May	June	July	August	September	October
ET (mm)	0,5	1	2	3	3,5	3	2

During the spring months due to the snow melting 10-15 mm are added to the previous soil humidity.

The advantage of these methods consists in the rapidity of obtaining the results, an important condition for forecasting hydric dangerous events. Thus when the forecast of some abundant and high intensity rain is achieved and when the previous conditions of the soil humidity are known the amplitude of the floods can be anticipated (in terms of water flow, volume, debit) before they take place.

The analysisof the factors which determine the soil humidity with the aid of GIS technology

*The factors which influence the reserves of water from the soi*l

When studying the water reserves from the soil one must consider as many parameters as possible so that the contour of a clear imagine of the actual process is produced. The main elements which influence the moistening process are: the soil characteristics of the land, the meteorology (precipitations, temperature, humidity, air humidity, the wind etc), the morphologic and morphometric characteristics, the land use.

Among the climatic characteristics the precipitations are of direct importance as they influence foremost through quantity and duration or intensity etc. The air temperature, the relative humidity, the wind speed and the sun shining period are climatic parameters with direct influence on the evapotranspiration process.

The database used for this study is represented by the daily mean precipitation values, recorded at the Cluj-Napoca meteorologic station, during the March- September period 2007 (214 days (fig.1).

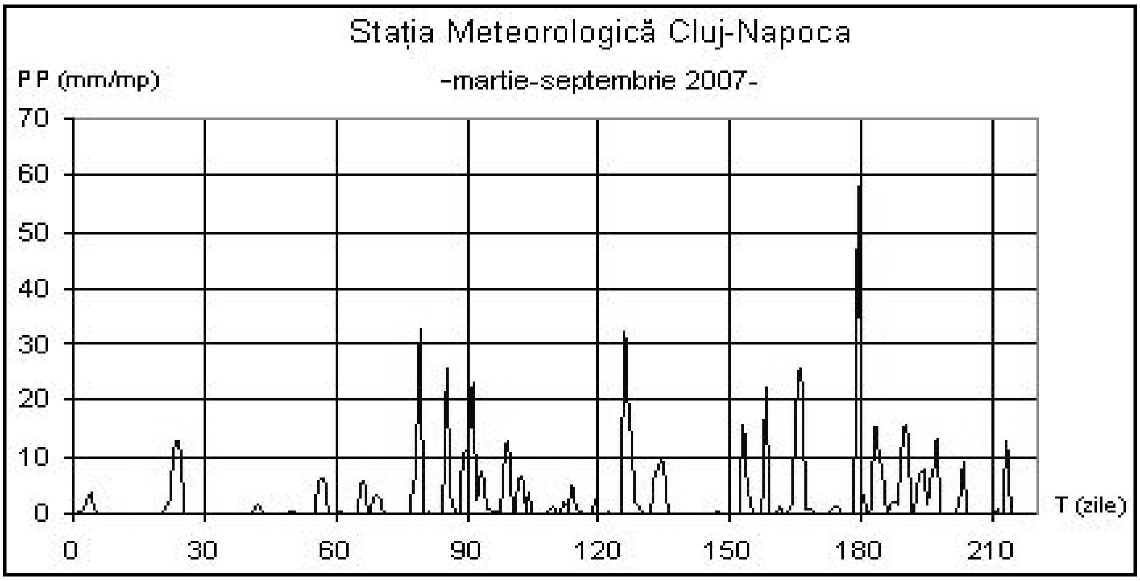

Figure 1. *The evolution of the daily mean precipitations within the studied area*

The soil cover (fig.2) represents the physical support for a series of hydric processes: infiltration, evapotranspiration, surface flow, suprasaturation. A soil gets moistened easier or slower based on some characteristics which are inter-conditioned: texture, structure, porosity, permeability, infiltration capacity, speed of infiltration etc. The soil texture (fig 3) defined by the degree of fragmentation of the mineral part in components of different size is a fundamental element in the process of soil humectation. The texture is paramount for the permeability of the soil, for the infiltration and retention of water or for the infiltration speed.

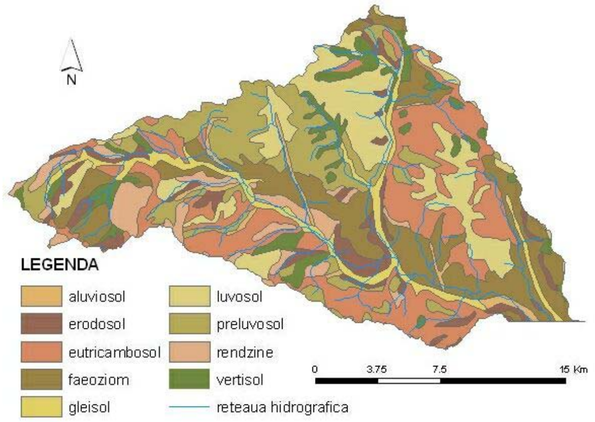

Figure 2 *The distribution of the soil types from the Nadăşului Basin*

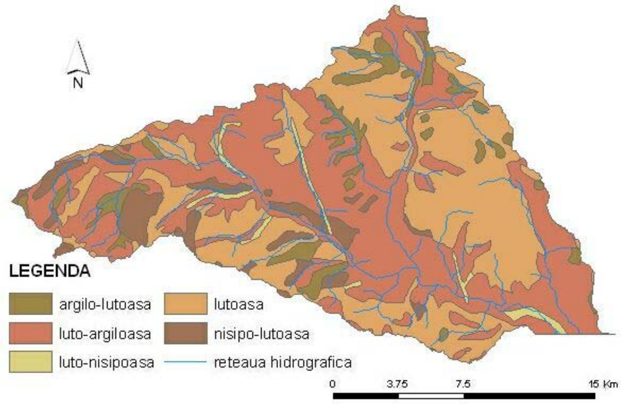

Figure 3 *The distribution of the soil structural classes from the Nadăşulu Basin*

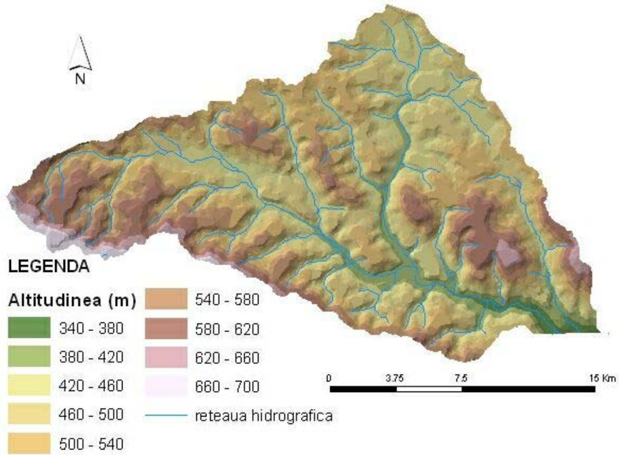

Figure 4. *The digital elevation model of Nadăşului Basin*

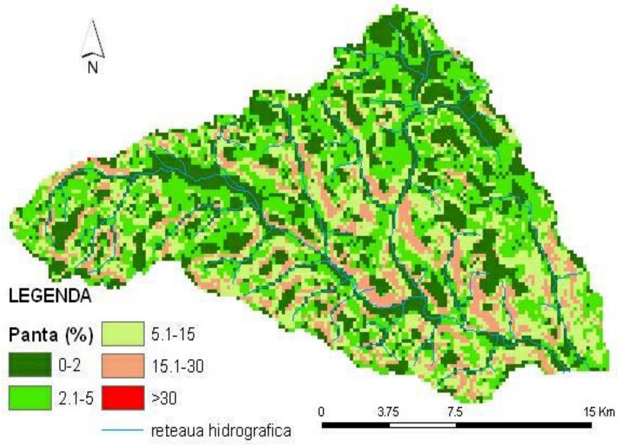

Figure 5 *The slope distribution in the Nadăşului Basin*

The terrain, trough altitude (fig.4) contributes to the distribution of precipitation sums according to the general law of precipitation increase based on altitude, and to the distribution of forest and soil types. The slope (fig.5) of the terrain influences the solidification process: the bigger the slope the faster the surface flow thus more erosion and accumulation. A small slope gradient accelerates the infiltration rate in the terrace area and on interbasin areas; in the water meadow regions the existence of phreatic layers at small depths and the hydric gain from the river bed increases the water reserves from the soil reducing the infiltration rate and favoring the development of the flow and sometimes of the pools during rains.

Different landuses (fig. 6) influence most of the surface hydric processes: the intercept of the precipitated water quantity, the infiltration, the flow, the evaporation, the soil erosion etc.

In the case of vegetation associations, their type, their size, their density and the canopy level condition the quantity of water that reaches the soil surface, the speed of the falling water drops, the magnitude of the soil –water clash, the accumulation time, the flow speed etc.

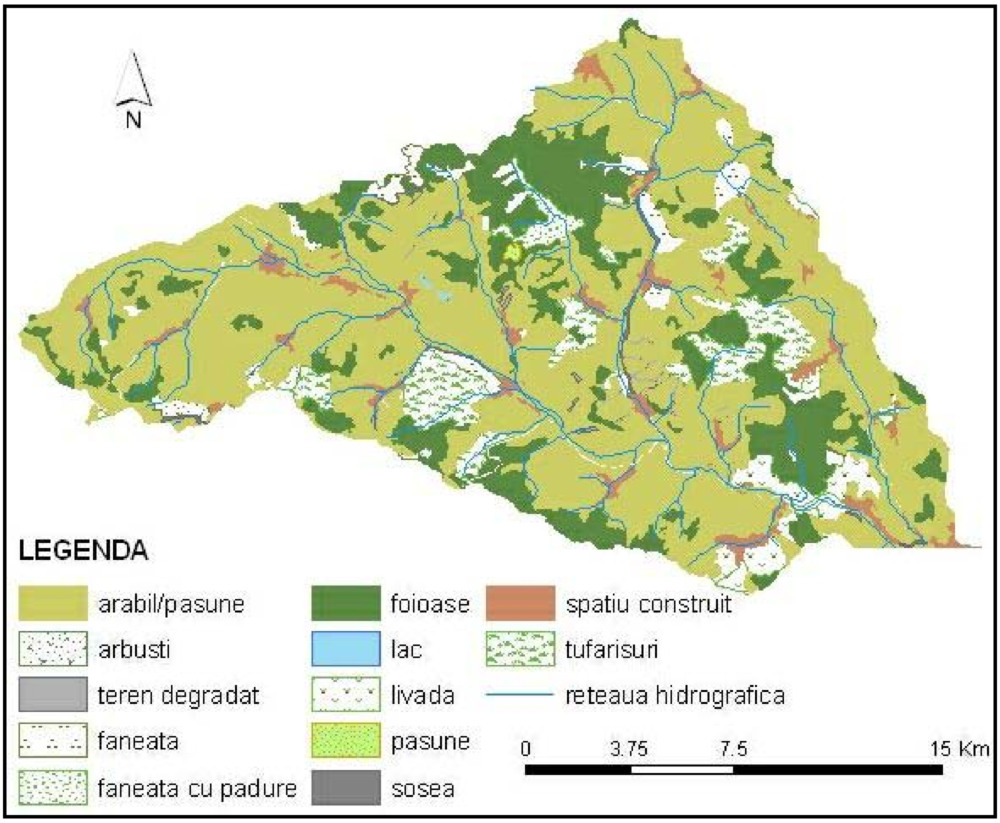

Figure 6. *The Nadăşului.* Basin Landuses

A land covered with forests will be less predisposed to powerful floods during the vegetation period than a piece of land without vegetation (ex. a coal quarry) because as compared to the latter it hosts the following processes: the retention of a certain quantity of water by the canopy and then through soil infiltration, an increase in the accumulation time, a diminishing of the water speed on the slope etc.

Used GIS functions

The graphical database referring to the considered parameters for the estimation of the soil water reserves was created with the aid of some extensions and functions specific for ArcGis 9 or ArcViewGIS 3.2a.displayed in **Table 4**.

The DEM was constructed by computing the TIN from digitized topographic maps 1:100.000.

The layer regarding the soil typology was obtained by digitizing soil maps 1:200.000. The classification was adapted to the new classification system (SRTS 2000). The landuse layer was digitized from topographic maps 1:100.000.

Table 4. *GIS functions used in analyzing the parameters which condition the water supply from the soil*

Used extension	**Used function**	**The obtained result**
3D Analyst	*CreateTIN*	DEM
Spatial Analyst	*SurfaceAnalysis→Slope*	Slope map
	SurfaceAnalysis→Aspects	Exposure map
	Interpolate to Raster	The interpolation of a point theme
AGWA (for ArcViewGIS 3.2a)	*DelineateWatershed*	Basin delineation
		The determination of the morphometric parameters of a hydrographic basin (perimeter, surface, mean slope, the length of the main river bed etc.)
Geostatistical Analyst	*Geostatistical Wizard*	The interpolation of a point theme

Processing of the data andobtained results

This part of the study aims at applying the methods presented in the second section. The months for which the calculus was computed are: March, April, May, June, July, August, and September 2007. As far as the API model is concerned the $\mathbf{K_t}$ parameter was given a value of 0,85, corresponding to the latitude range and the physical – geographic conditions specific for the analyzed perimeter.

In such manner the values of the soil water reserves were obtained for each of the days included in the analyzed period (fig. 7).

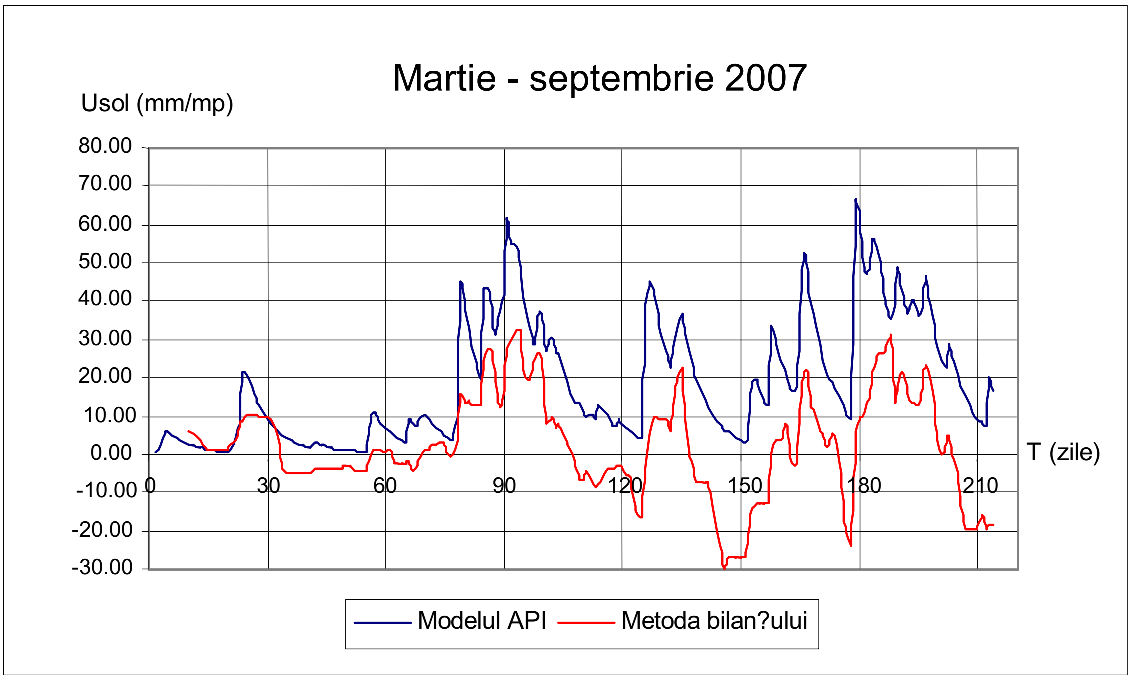

Figure 7. *The evolution of the soil humidity in the Nadăşului Basin determined with the aid of the two methods*

It must be pointed out that as compared to the API method, the hydric balance method produced a series of values below 0 which can be explained by the:

- ✓ the reduced quantity of precipitation;
- ✓ the large number of days without precipitations;
- ✓ the lack of a significant gain from the snow layer;
- ✓ very high evapotranspiration, during a period with high temperatures (many cases > 35°C);
- ✓ the reduction of the subterranean water reserves;

Both of the used methods can be characterized by results expressed in evolution curves similar in shape, growth and decrease moments for the same days, the differences being of quantitative nature.

For a more exact outline of the differences between the two methods we computed a subtraction between each daily humidity value of the two methods. The result (the deviation) is presented in fig. 8.

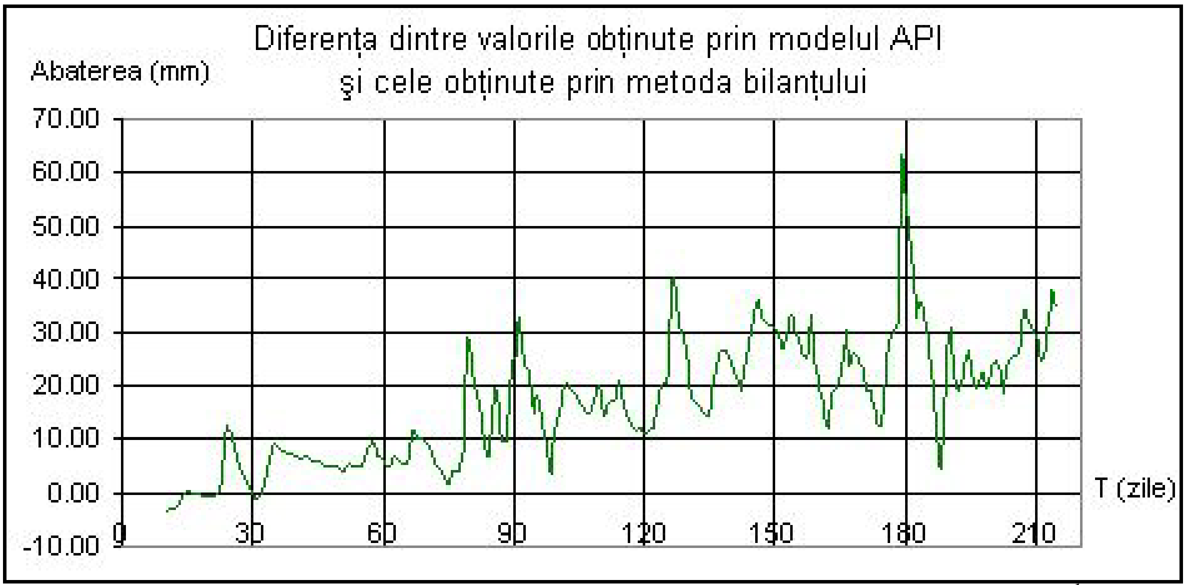

Figure 8. *The deviations between the API curve and the hydric balance curve in the 10^{th} March – 30^{th} September 2007 period*

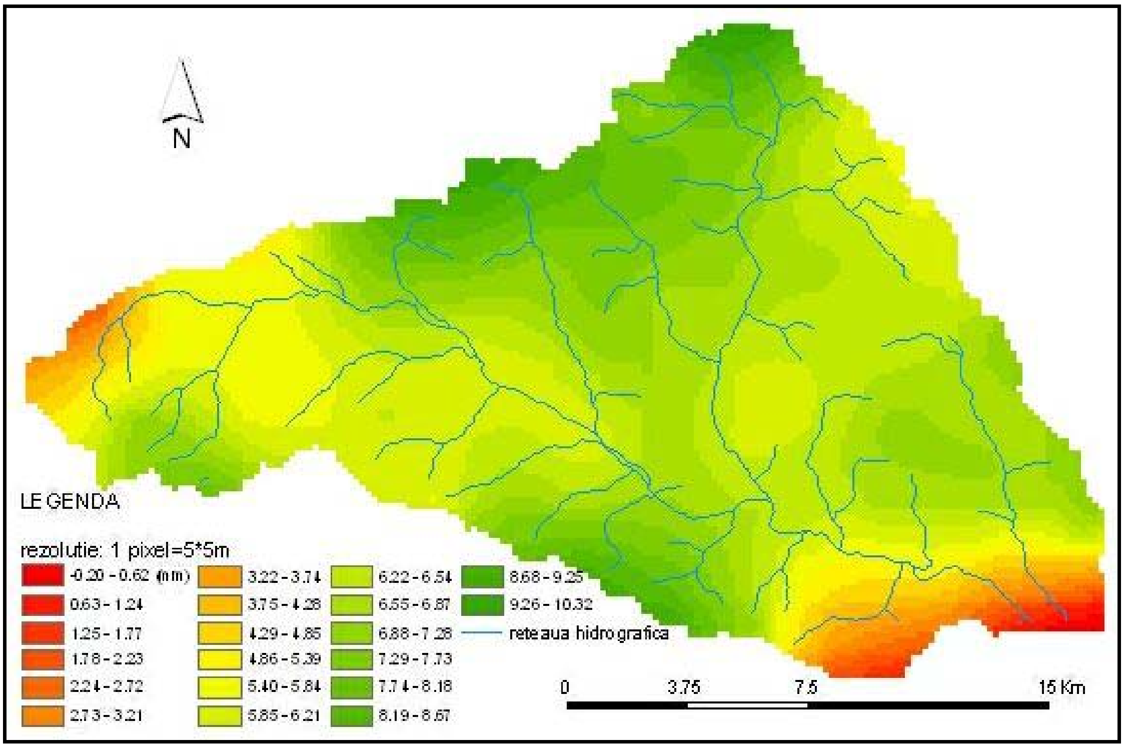

Figure 9. The *Nadăşului Basin The spatialization of the soil humidity values for the spring season of 2007 with the aid of the hydric balance method*

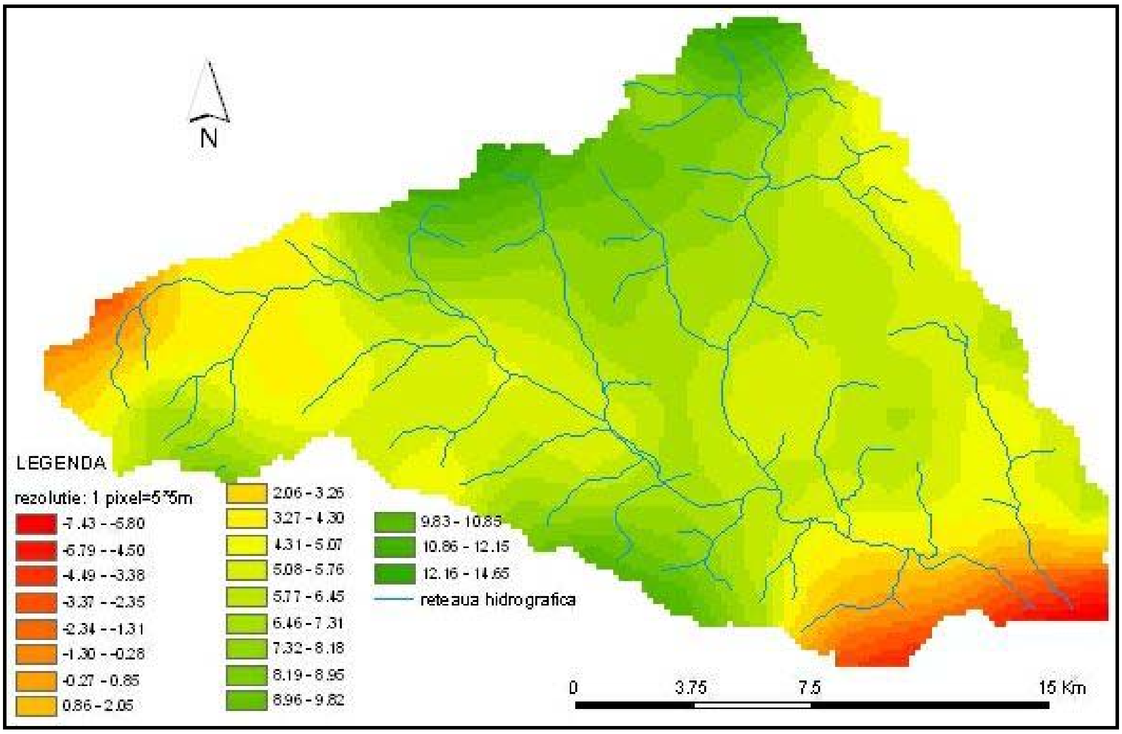

Figure 10 The *Nadăşului Basin The spatialization of the soil humidity values for the summer season of 2007 with the aid of the hydric balance method*

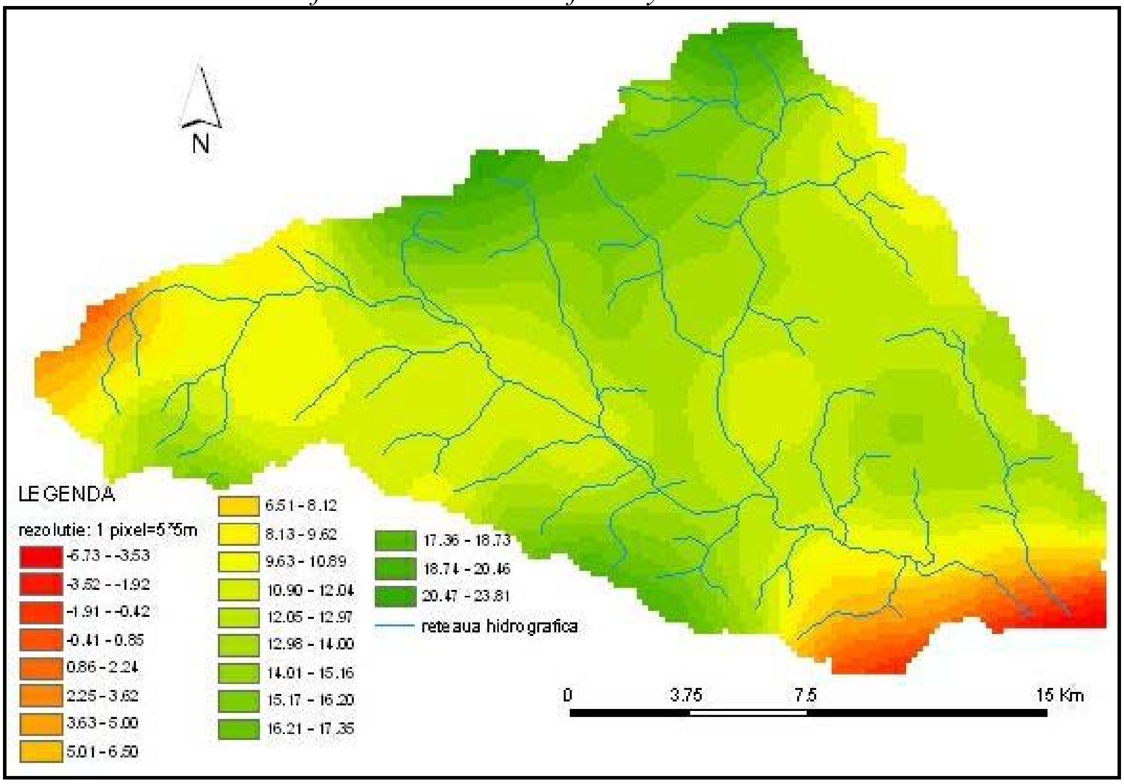

Figure 11 The *Nadăşului Basin The spatialization of the soil humidity values for the month of September 2007 with the aid of the hydric balance method*

For a better spatial image of the humectation degree of the soil the soil humidity was computed using around 100 points across the basin. The computed value in a point represents the mean of the daily values of a calendar season (spring, summer, the beginning of autumn)..

The flow coefficient for each point was the first parameter to be determined, based on the terrain slope, the landuse, the soil texture (based on Frevert's). The coefficient was further used in the hydric balance formula.

After spatially representing the points, we created a deterministic interpolation of these points with the use of the **G**eostatistical **A**nalyst extension. Such an interpolation is called **L**ocal **P**olynomial **I**nterpolation and it was executed with a resolution of 5 m. Three layers containing the distribution of the soil humidity values at seasonal level were thus obtained (fig. 9, 10, 11).

Conclusions

The purpose of this study was the identification of some quick alternatives for the determination of the water reserves from the soil without the need of field studies and laboratory analysis in an attempt of reducing the estimation time for a flood event.

Table no .5 summarizes the strong points and weaknesses of the two methods applied in the result materialization phase.

Table 5. *The strong and weak points of the two methods of estimating the soil water resources*

The used method	**Strong points**	**Weak points**
API	✓ the speed in obtaining the results; ✓ time efficient and the technically portable;	✓ the small number of parameters considered; ✓ the non-inclusion of some parameters regarding the loss of water from the soil;
Metoda bilanțului	✓ the speed in obtaining the results; ✓ time efficient and the technically portable; ✓ the high number of input parameters; ✓ the inclusion of some soil water loss parameters (evapotranspiration, the number of days without precipitations); ✓ the attenuation of the water infiltration by taking into account certain flow coefficients;	✓ the non-inclusion of some input parameters (the gain from subterranean water, the exact water quantity from snow melting etc.);

The **GIS** techniques used made possible the spatial analysis of the process, mainly from the point of view of the parameters which influence the soil moisture.

By analyzing the results obtained by using the two methods we identified:

- a period with very low values of soil humectation in the next 20 days of March and for the most of April but also in the second half of June and July due to the reduced sums of precipitations and constantly high temperatures; the hydric balance method pointed out even negative values for these periods. Such a situation can be characterized as a "humidity deficit"
- an increase in the soil humidity in the last third of spring (May) as well as in the end of the summer and the beginning of autumn with values above 40 – 50 mm/day (the hydric balance method) or even above 60 mm/day (the API model);
- an increase in the soil humectation directly proportional with the increase in altitude as the flow coefficient decreases;
- an increase in the values of soil humectation as the slope decreases;
- very low values of water resources in the lower basin due to the large extent of the built space;

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