Bulletin of the *Transilvania* University of Braşov • Vol. 3 (52) - 2010
Series II: Forestry • Wood Industry • Agricultural Food Engineering

HYDROLOGICAL MAPPING OF THE VEGETATION USING REMOTE SENSING PRODUCTS

M.D. NIȚĂ[1] I. CLINCIU[1]

Abstract: *This paper proposes a new method based on FCD (Forest Cover Density) model, which maps the vegetation taking into consideration the canopy density. The critical analysis of well-known methods from Romanian literature, concluded that the age and stand consistency are the main factors in hydrological mapping of the vegetation. In the new technique we integrated several vegetation indexes, which made possible a hydrological mapping based entirely on remote sensing products. We have applied the new method in Upper Tărlung Watershed, and the results obtained revealed a strong correlation with the results offered by classical methods.*

Key words: *hydrological mapping, remote sensing, vegetation index.*

1. Introduction

The hydrological mapping of forest vegetation is an activity used for some hydrological parameters determination. These parameters characterize the vegetation for mathematical quantification of the hydrological processes which happen within the hydrographic watersheds.

The most common synthetic quantification of the hydrologic mapping of the vegetation is represented by the flow coefficients. These coefficients are calculated after the analysis of the factors that influence the hydrological balance between the flow and the rain [1].

According to the peak discharge calculation methodology of small, predominantly forested watersheds, the flow coefficient estimation is based on the evaluation and quantification of retention and infiltration at a specific rain, under conditions encountered in watershed [1].

The characteristic coefficient for the hydrological categories established by the hydrological mapping system proposed by Apostol in 1972 plays a very important role in the estimation of retention. This mapping system has been completed in 1973-1987 period by M. Ionescu, P. Dumitrescu and N. Lazăr, and it was adapted by Păcurar for computer application in the GWBASIC programming language [2]. In the next period, the dichotomic schematics used in the structure mentioned in [1] allowed the development of computer based mapping modules that can be found in today's geographic information systems like IDRISI [2] or ESRI ArcMap [5].

[1] Dept. of Forest Management Planning and Terrestrial Measurement, *Transilvania* University of Braşov.

The mapping system proposed by Apostol and the method proposed by Păcurar require as input data certain information about the watershed conditions which can be found in the Forest Management of that area. The system proposed in 1972 did not offer a clear methodology of using the mapping system, the schematics "having a qualitative nature and include descriptive elements for each category and subcategory" [2]. Therefore, the method proposed by Păcurar offers a clear structure, developed for computer application, based on quantitative facts. The Păcurar method was created specifically to be applied in programs which work with punctual data as well as in GIS environments that work with gridded data.

The mapping systems mentioned above use as input data information about the status of the soil, the stand age, the stand consistency and the production class. With the aid of the last criteria, these systems succeed in characterizing the forest influence to the flow process, better than the mapping system proposed by Frevert.

The spatial and temporal precision of the simulation as well as the quality of the results are in direct link with the data used as input. Therefore, by using the data retrieved from the forest management plan, the method can encounter several temporal and spatial difficulties:

- First, the forest management plan is updated once at every 10 years, and during this period modifications may appear in the structure of the vegetation within the studied watershed;
- Second, provided the application of a silvicultural work within a large sub-department is known, the development of the work cannot be characterized and determined thoroughly (ex. the position of stripes from striped clear-cuts, the position of patches from progressive cuts);
- Finally, another spatial issue is represented by the precision of the measurement of subcompartment borders.

2. Objectives

The calculus of flow coefficients is influenced directly by the hydrological mapping of vegetation. Irrespective of the methods they employ - such as using a specific term (ex. S term in SCS-CN method, which represents the maximum value of the sum between the total retention and the infiltration quantum); or using representative land cover categories (ex. Apostol method); or using simplified procedures such as the Frevert method or the Moțoc method - the mapping procedures are governed by the same developing directions:

- Each method takes as main data input the presence or absence of the vegetation;
- The land cover is categorized in the following main categories: forests, pastures, agricultural lands and bare soil lands;
- Qualitative and quantitative information is used for the definition of further categories and/or subcategories.

In the present paper the main objective is the realization and validation of a new method of hydrological mapping of the vegetation based on information from remote sensing products.

The characterizing elements presented above influence each other; however, in many cases the stand age and the consistency influence decisively the other elements. Therefore, the usage of satellite images, aerophotograms or remote sensing products in hydrological mapping of the vegetation can contribute significantly to the estimation of principal characterization elements (age and consistency).

Temporal and spatial problems that appear in traditional methods can be minimized with the help of the new technique, which is based on remote sensing products.

3. Material and Methods

The hydrological mapping method of the vegetation is based on the FCD model structure, which was developed [3], [4] on data input taken from Landsat TM satellite images. The FCD model analyzes the vegetation on the basis of four vegetation indexes: Advanced Vegetation Index (*AVI*), Bare Soil Index (*BI*), shadow Index or scaled Shadow Index (*SI, SSI*) and Thermal Index (*TI*).

The results obtained after the model run offers information for monitoring the canopy density, indicating the forest status in the acquisition time of satellite image.

The advanced vegetation index (AVI) is related to the NDVI index, but is better that the latter in highlighting subtle differences in canopy density. AVI uses the power degree of the infrared response and this characteristic is making AVI more sensitive to forest density and physiognomic vegetation classes. In our research, AVI has been calculated using the Equation (1):

$$\mathrm{AVI} = \sqrt[3]{(\mathrm{B}4+1)\cdot(256-\mathrm{B}3)\cdot \mathrm{B}43}\,, \quad (1)$$

where: B3, B4 - the 3rd and the 4th band of Landsat image; B43 - the difference between B4 and B3.

Bare soil areas, fallow lands and vegetation with marked background response are enhanced using the bare soil index. Similar to the concept of AVI, the bare soil index (BI) is a normalized index which separates the vegetation with different background visibility in *completely bare, sparse canopy* and *dense canopy*. In our research we have used the following formula to calculate BI:

$$\mathrm{BI} = \frac{(\mathrm{B}5+\mathrm{B}3)-(\mathrm{B}4+\mathrm{B}1)}{(\mathrm{B}5+\mathrm{B}3)-(\mathrm{B}4+\mathrm{B}1)}\cdot 100+100, \quad (2)$$

where: B1, B3, B4, B5 - the 1st, 3rd, 4th and 5th band of LANDSAT image.

The crown arrangement found in the forest stand leads to a shadow pattern that affects the spectral responses. The shadow index SI quantifies this pattern and is able to differentiate between young stands and mature stands. The young stands have a lower canopy shadow index (SI) compared to the mature natural forest stands. The older forest stands show flat and low spectral axis in comparison with the open area. SI has been calculated using Eq. (3):

$$\mathrm{SI} = \sqrt[3]{(256-\mathrm{B}1)\cdot(256-\mathrm{B}2)\cdot(256-\mathrm{B}3)}\,, \quad (3)$$

where: B1, B2, B3 - the 1st, 2nd, 3rd band of LANDSAT image.

For the mapping method application a LANDSAT TM, with the acquisition year 2009, was downloaded from LANDSAT repository.

4. Results and Discussions

For validation, the method for hydrological mapping of the vegetation was applied in Upper Tărlung Watershed, upstream the Săcele lake.

The procedure of hydrological mapping method contains the following five steps:

1. Satellite image calibration;
2. Vegetation indexes calculation: AVI, BI and SI;
3. Division of the vegetation index values in three distinct classes (Low, Medium, High), taking into consideration the value variance;
4. Combination of the vegetation index classes;

Vegetation index combination identification and vegetation categorization in the hydrological categories proposed by Apostol (Table 1).

The vegetation indexes have different behaviour as it follows (Figure 1):

- AVI offer information about all vegetation elements, both for forested areas and pastures;

Composed vegetation index classes grouping in hydrologic categories Table 1

Specifications	Hydrologic category				
	A	**B**	**C**	**D1**	**D2**
AVI – SI – BI combination	H-H-L; H-H-M; H-H-H	L-H-L; M-H-L; M-H-M	L-M-L; L-M-M; L-H-M; M-L-L; M-L-M; M-M-L; M-H-H	M-M-M; M-M-L; H-L-M; H-L-H; H-M-L; H-M-M; H-M-H	L-L-L; L-L-M; L-L-H; L-M-H; L-H-H; M-L-H
where: H = High; M = Medium; L=Low					

• SI takes higher values with the decrease of the forest density;
• The increase in the percent of bare soil determines a subsequent increase in the value of BI.

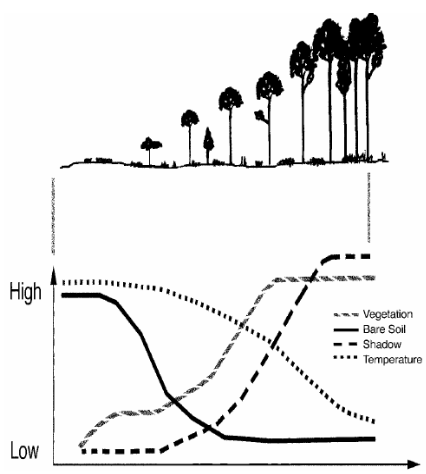

Fig. 1. *Vegetation indexes characteristics against the forest condition* [4]

In method application, five hydrological classes are obtained according to those proposed by Apostol.

In order to combine the vegetation indexes, they were divided in three classes: *low, medium* and *high*, according to the statistical distribution shown in Figure 2.

After reclassification, the final step in mapping the vegetation is the hydrological class extraction. The method is developed on a raster calculation algorithm, which creates complex codes to every pixel, from simple codes (Table 1).

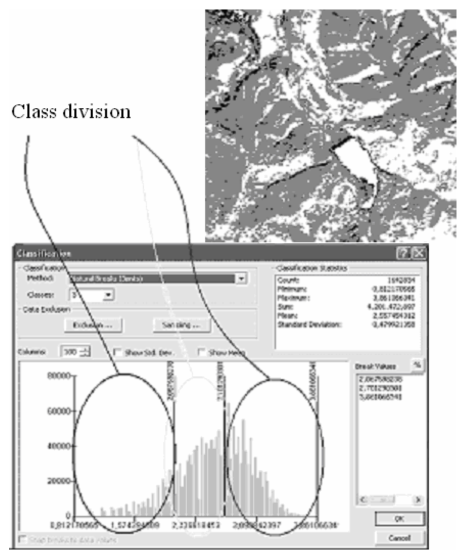

Fig. 2. *Vegetation index class division*

The result is a thematic raster which contains on every pixel the hydrological class of the vegetation located in those coordinates (Figure 3).

After cropping the Landsat image on the region of interest, the pixel frequency distribution of the product offered by the proposed method shows a high percent of forest vegetation in the area. This is one of the advantages of the results offered by the method, which fulfils the first condition of classical methods, namely to identify the presence or the absence of the vegetation. Knowing, at pixel level, the land cover category offers the first information both quantitative and qualitative on forest degree in the studied watershed.

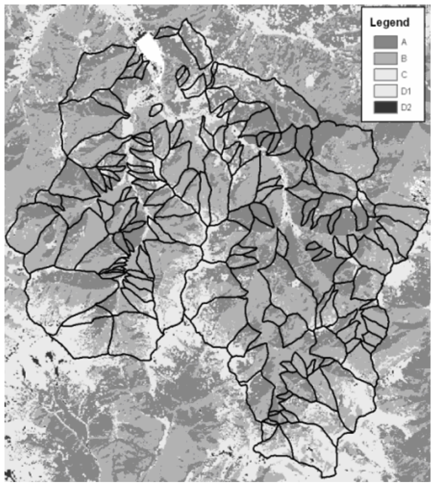

Fig. 3. *Hydrological classes thematic raster for Upper Tărlung Watershed*

In the Upper Tărlung Watershed area 85% was identified as forested and 31% fell in category A, 51% fell in category B and 3% in category C (Figure 4).

The rest of the area was identified as being comprised of 14% pastures and 1% bare soil (i.e. rocks, roads and agricultural land).

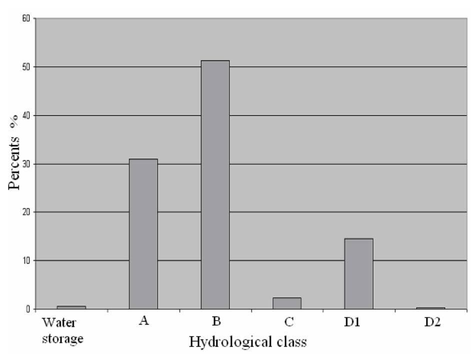

Fig. 4. *Hydrological class distribution of vegetation from Upper Tărlung Watershed*

Having the land cover category at pixel level offers easy manipulation of data. From this point, it was easy to determine the flow coefficient determination on the small watersheds from Upper Tărlung Watershed.

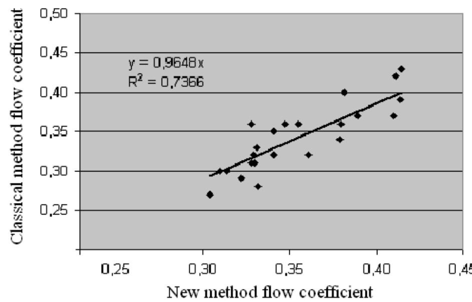

Fig. 5. *Correlation between Frevert coefficients and new method coefficients*

The flow coefficients of 23 watersheds were calculated with classic methods and the new method and their values compared.

The results of the comparison of showed a high correlation between traditional methods and the new method, as can be seen in Figure 5.

5. Conclusions

By adapting the application method from FCD model for hydrological mapping of the vegetation a new method was created based on remote sensing products. The results of the method put it on a quality scale between Frevert method (which uses few data input) and Apostol method (which uses many data taken from forest management).

Regarding the applicability, the proposed method proves to have a very high precision when applied to extended areas.

The high correlation between the flow coefficient values determined from forest management data and those determined with the new method, gives the proposed method a high level of trust.

Using the remote sensing products offers advantages, the most important being the actuality of the data. Using vegetation indexes, the obtained results offer an accurate mapping of the real situation in the field, indirectly improving the flow coefficient calculation and implicitly, the peak discharge prediction.

Another advantage is given by the high degree of coverage of the product offered. The application of the method has a minimum unity with 0.1 ha area, which makes it suitable for the mapping of small areas. At the same time, the product gives the possibility of mapping larger zones with the help of LANDSAT images.

The method shows some disadvantages at processing (level of expertise in remote sensing must be intermediate) and interpretation (clouds occurrence); nevertheless, it offers a better alternative of hydrological mapping of the vegetation especially in zones where is no GIS data is available or where such data are out of date.

The offered product ensures easy manipulation in GIS in raster format. Furthermore, the proposed method proves to be useful not only in small watersheds but in larger basins too.

Acknowledgements

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/6/1.5/S/6.

References

1. Clinciu, I.: *Corectarea Torenţilor* (*Torrent Control*). Braşov. *Transilvania* University Publishing House, 2001.
2. Pacurar, V.D.: *O nouă metodă de cartare hidrologică a terenurilor forestiere utilizând sistemele de informaţii geografice* (*A New Method of Hydrological Mapping of Forested Lands using Geographic Information Systems*). In: Revista Pădurilor **2** (2005), p. 28-31.
3. Rikimaru, A.: *Landsat TM Data Processing Guide for Forest Canopy Density Mapping and Monitoring Model*. In: Proceedings of ITTO Workshop on Utilization of Remote Sensing in Site Assessment and Planning for Rehabilitation of Logged-Over Forest, Bangkok, Thailand, July 30-August 1, 1996, p. 18-24.
4. Rikimaru, A., Roy, P.S., Miyatake, S.: *Tropical Forest Cover Density Mapping*. In: Tropical Ecology **43** (2002) No. 1, p. 39-47.
5. Tamaş, S., Clinciu, I.: *Cercetări privind posibilităţile de utilizare a sistemelor de informaţii geografice* (*GIS*) *în fundamentarea hidrologică a proiectării lucrărilor de amenajare a bazinelor hidrografice torenţiale.* (*Research on Usage of GIS in Hydrological Substantiation of Management Works in Hydrographic Torrential Watersheds*). Scientific Report, Braşov. *Transilvania* University Publishing House, 2006.