USING GIS TO IDENTIFY POTENTIAL AREAS SUSCEPTIBLE TO FLOOD. CASE STUDY: SOLONEŢ RIVER

V. TIPLEA [1], S. TODICĂ[1], IOANA SIMEA[2],
T. ANGHEL[2], IONELA GEORGIANA GAVRILĂ[2]

ABSTRACT. – Using GIS to Identify Potential Areas Susceptible to Flood. Case Study: Soloneţ River. In this study, we aim to analyze the impact of different peak flows in territory and also a better understanding of the dynamic of a river flow. The methodology used for flood zone delimitation is based on a quantitative analysis model which requires the use of mathematical, physical and statistical operations in order to emphasize the relations between the different variables that were implied (discharges, grain size, terrain morphology, soil saturation, vegetation etc.). The results cannot be expected to be completely accurate but can provide a good representation of the process. Validation of results will inevitably be difficult and should be measured in the field. The information resulting from this study could be useful for raising awareness about both hazards and possible mitigation measure, a key component of disaster risk reduction planning.

Keywords: peak flow, discharges, quantitative model, hazard, GIS.

1. INTRODUCTION

The Soloneţ river, which is the right tributary of the Suceava river, crosses from west to east the morphological contact between Obcinele Bucovinei and Sucevei Plain (also known as Piemontul Marginea-Ciungi). Our study area is located in the lower sector of the river, at the confluence with Suceava river, near the Parhauti locality.

Characteristic of this area are narrow and deep river beds in which meander phenomena often occur. The erosion in this sector is increased, the flow of sediments being noteworthy especially during floods. At the contact with the Suceava Plain, the sudden decrease of the river bed slope generates a high quantity of sediments. Another interesting aspect of this area is the fact that although floods have a high frequency, the river beds remain constant in their direction.

In the case of Soloneţ river the analysis of runoff slopes requires a better understanding of the sediments transport features (volume, granulometry), as well as the way in which important tributary (Hotari, Hinata) directs the rivers course.

The formation of meanders is the result of an intense lateral erosion process, in terms of sediments transport with small granulometry. In this way a

[1] Technical University of Cluj-Napoca, Faculty of Civil Engineering, Romania, e-mail: vasiletiplea@yahoo.com, todica_sandu@yahoo.com
[2] "Babeş-Bolyai" University, Faculty of Geography, 400006 Cluj-Napoca, Romania, e-mail: ioana_simea@geografie.ubbcluj.ro, anghel_titu@geografie.ubbcluj.ro, ionela_gavrila@geografie.ubbcluj.ro

state of equilibrium is created between the runoff slope (which directly influences the flow rate), the liquid and solid flow, the resistance to erosion of the banks and the contribution of the tributaries.

The sinuosity coefficient of the Soloneţ river varies, between 1,2 in the upper sector (flysch zone) and 1.62 right after the confluence with the Hotari river. After this it grows progressively at values over 2, downstream of the confluence with the Cajvana river.

During the last decades analysis indicates that the sinuosity parameter of the Soloneţ river grew significantly between 1961 and 1978 (from 1.55 to 1.88), followed by a decrease between 1978 and 2005 (from 1.88 to 1.76).

The hydric factors determine the start and evolution of the slope modelling through the value of hydrodynamic and hydrostatic forces. The hydrologic conditions of the rivers from Marginea-Ciungi Piedmont has a torrential character as a result of its position in an area with a temperate climate and continental influences.

The summer flow is characterized by values situated well below the multiannual average. The uniformity of the runoff regime is interrupted by floods, which determine an increase in annual flow values.

During the high summer floods (july-august), the action of rivers waters is stronger because of the increased flows, that sometimes are up to a 100 times higher than the multiannual average.

The highest water flows recorded on the Soloneţ river took place during the years 1991 (298m/s on the 28th of July) and 2005 (149 m/s on the 19th of August).

In order to analyze the maximum flows recorded on the Soloneţ river we used the Log-Pearson Type III Distribution method. We also determined the reccurence period and the probability of exceeding the maximum flows in the near future (Tabel 1).

Thus a flow of 298 m/s, that occured on the Soloneţ river during the year 1991, can only be equaled or exceeded, in average, once every 27 years. For example a flow of 2.9 m/s (double the multiannual average) can be equaled or even exceeded once a year (the annual probability of exceeding being 96.3%).

On the Soloneţ river we can estimate that a maximum flow of 490 m/s can only be reached once every 200 years.

2. METHODOLOGY

Our study aims to determine the areas affected by floods on Soloneţ river. Therefore, we have simulated 6 floods with flows between 2.9 cm/s and 298 cm/s.

First, we have generated a high resolution DEM, using topographic map sheets (at a scale of 1:5000). Operating at a medium resolution of 1-5 m is fine enough to allow the channel to span several cells instead of operating within one, generating a more detailed fluvial representation. This resolution may also allow representation of different grainsizes, slope and hydrological processes to operate within the same framework for an area.

Tabel 1. ***The reccurence period and the probability of exceeding maximum flow***

Rank	Year of peak flow	Peak flow value Q(m^3/s)	Return Period (years)	Exceedence Probability
1	1991	298	27.00	0.037
2	2005	149	13.50	0.074
3	1984	121	9.00	0.111
4	2002	91.5	6.75	0.148
5	1981	88.5	5.40	0.185
6	1988	83.6	4.50	0.222
7	1985	73.1	3.86	0.259
8	2001	72.4	3.38	0.296
9	2004	69.1	3.00	0.333
10	1998	51.4	2.70	0.370
11	1996	42.2	2.45	0.407
12	1993	39.8	2.25	0.444
13	2003	37.5	2.08	0.481
14	1982	33.2	1.93	0.519
15	1989	33	1.80	0.556
16	1983	27.3	1.69	0.593
17	1997	26.2	1.59	0.630
18	1992	25.1	1.50	0.667
19	1980	24.1	1.42	0.704
20	1999	23	1.35	0.741
21	2000	13.1	1.29	0.778
22	1987	7.58	1.23	0.815
23	1986	6.16	1.17	0.852
24	1995	4.6	1.13	0.889
25	1994	4.42	1.08	0.926
26	1990	2.9	1.04	0.963

There are several commercial packages available for creating DEM's, but in this instance, the TOPOGRID command in ARC-INFO was used. This function is designed specifically for the interpolation of a hydrological DEM from contour data. It identifies areas of maximum local curvature and slope to create a network of streams and ridges, ensuring hydrogeomorphically correct output. TOPOGRID also removes topographic sinks and hollows. This is necessary as many artificial sinks are produced by errors interpolating the DEM from contour data (Goodchild and Mark, 1987; Hutchinson, 1989).

A problem of our study was represented by the exact configuration of major and minor river beds in the previously generated DEM. For this, a series of cross sections were created along the Soloneţ river bed, those results being integrated in the DEM. Thus, we can say that the resulted DEM fairly showed the reality from field.

The DEM is represented by an array of uniform square grid cells. Each grid cell has properties like initial values for elevation, water discharge, water depth and grainsize fractions. For each timestep or iteration, these values are updated in relation to the immediate neighbours according to laws applied to every cell. These laws fall into four groups covering hydrological, hydraulic, erosion and slope process modelling.

The next step of our study consisted in simulating floods by introducing real or fictional volumes of water from upstream to downstream. The insertion of fictional flows was done in order to simulate only the extreme flows that could lead to floods. This was possible through the creation of a model implemented using GIS techniques (ArcGis, ArcInfo, GRASS and different scripts).

With the help of this model, the soil saturation for an individual cell (J_t) is calculated. The saturation for the next time-step is then calculated (J_{t+1}), but for this an additional parameter is carried over, $j_{t,}$ which before each calculation is set to the previous iterations j_{t+1}. Then, if the rainfall rate (r) equals 0, J_{t+1} is calculated according to next equation.

$$j_{t+1} = \frac{j_i}{1 + \left(\frac{jT}{m}\right)}$$

$$J_{t+1} = \frac{m}{T}\log\left(1 + \frac{j_t T}{m}\right)$$

If rainfall is not equal to 0, next equation is used.

$$j_{t+1} = \frac{r}{\left(\frac{r - j_t}{j_t}\right)\exp\left(\left(\frac{(0-r)T}{m}\right)+1\right)}$$

$$J_{t+1} = \frac{m}{T}\log\left(\frac{(r - j_t) + j_t \exp\left(\frac{rT}{m}\right)}{r}\right)$$

Within these expressions, *m* is the key variable, controlling the rise and fall of the soil moisture deficit, effectively the exponential soil water parameter in TOPMODEL (Beven and Kirkby, 1979). The runoff is multiplied by the grid cell size to obtain discharges which is added to every cell.

Thus, for quick response flow, such as saturation excess overland flow produced on a variable contributing area, the duration of flow is likely to be critical only in small basins. Indeed, for larger ones where channel routing effects become increasingly important, overland flow may be treated as effectively reaching the channel within one time step. It is, however, very important to accurately model the quantity of quick response flow and the time at which it is produced. This will involve modelling the dynamic response of a variable characterizing the surface soil layer.

The overall timing of infiltration will certainly be important, but the characteristics of the infiltration store will be less important than those of the subsurface store, which may directly shape the overall hydrograph.

The exact structure of the model must necessarily reflect the types of hydrological characteristics that are quick, convenient and economic to measure for a particular basin. These include the topographic structure together with infiltration rates, overland and channel flow velocities, a small number of discharge measurements and some simple measurements of the soil hydrological characteristics.

Then, for each grid cell, a runoff threshold is calculated which is based upon the amount of water that will infiltrate through the soil, a balance of the hydraulic conductivity (K), the slope (S) and the horizontal spacing (Dx).

$$Threshold = KS\left(Dx\right)^2$$

This is then subtracted from the soil saturation produced from first two equations and the proportion above is treated as runoff, that below as subsurface flow. This subsurface flow is routed using a multiple flow algorithm as described by Desmet and Govers (1996).

$$Q_i = Q_0 \frac{S_{in}^x}{\sum S_i^x}$$

Here Q_i is the fraction of discharge delivered to the neighbouring cell $_i$ from the total cell discharge *(Q_o)* in m³ /s, according to the slope *S* between the cell and its relative neighbours *I*, numbering from *1-x* (*x* ranging from 3 to 8 depending on the number of neighbours).

3. RESULTS AND CONCLUSIONS

In order to simulate a flood we can either use the real data recorded that year or we can just insert a fictitious value for the flow. By inserting the daily values of the flows recorded along recent years on Soloneţ river, we obtained the simulation of the runoff process in normal parameters.

The simulation starts with the entering of values from upstream to downstream in order to fill the minor river bed progressively. Depending on the circulated flow, on each sampling, the value of the cells updates corresponding to the inserted flows.

The results that were obtained after the simulation of 6 floods are presented as follows. Once we insert fictitious flows the river starts to flood the lower areas of the minor river bed (small depressions, abandoned courses etc.). As the flow increases, so does the flooded surface of the river bed (fig. 1).

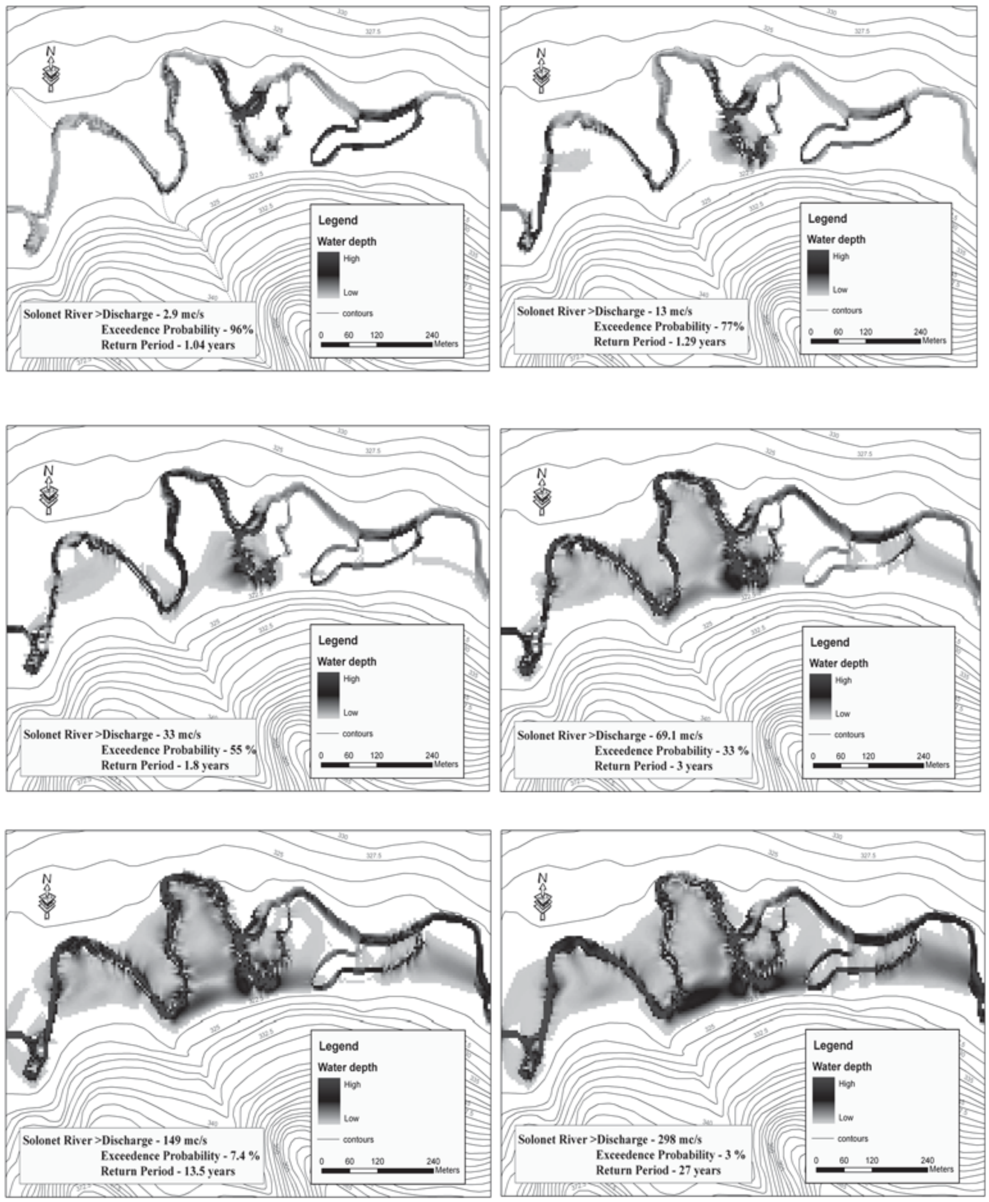

Fig. 1. ***Spatial distribution of flooded areas for 6 fictitious values proposed on Soloneţ River***

The importance of this simulation is that we can identify the areas which will be affected if the proposed values of the flow occur naturally on Soloneţ river. For our analysis, the potentially endangered surfaces vary between 11 230 m² (at a flow of 13 m^3/s) and 125 775 m² (at an extreme flow of 298n^3/s) (fig.2).

The model we used is perfectible, the outlook of the study consisting in validating results in the field and correcting software deficiencies. The damage from the floods may be reduced in two ways: either by modifying the hazard itself or by reducing the human susceptibility to it.

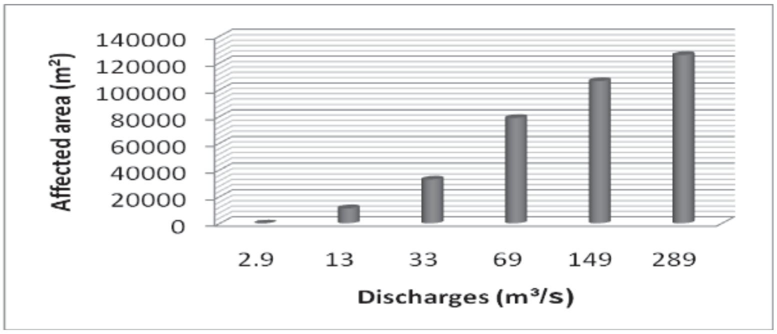

Fig. 2. ***The size of flooded areas at different values on Soloneț river***

Both ways require a mapping of the floods susceptibility. Such maps normally aim at providing a document that depicts the likelihood or possibility of new floods occuring on this river, and therefore helping to reduce future damages.

4. ACKNOWLEDGMENTS

This work was supported by Investing in people! PhD scholarship, Project co-financed by the SECTORAL OPERATIONAL PROGRAMME HUMAN RESOURCES DEVELOPMENT 2007 – 2013 Priority Axis 1 "Education and training in support for growth and development of a knowledge based society" Key area of intervention 1.5: Doctoral and post-doctoral programmes in support of research. Contract POSDRU 6/1.5/S/3 – „DOCTORAL STUDIES: THROUGH SCIENCE TOWARDS SOCIETY" Babeş-Bolyai University, Cluj-Napoca, Romania and Ph.D. scholarship, Project co-financed by the Sectoral Operational Program for Human Resources Development 2007 – 2013. Priority Axis 1. "Education and training in support for growth and development of a knowledge based society". Key area of intervention 1.5: Doctoral and post-doctoral programs in support of research. Contract No.: POSDRU/88/1.5/S/60185 – "Innovative Doctoral Studies in A Knowledge Based Society" Babeş-Bolyai University, Cluj-Napoca, Romania.

REFERENCES

1. Beven, K. J., Kirkby, M. J., (1979), *A physically based, variable contributing area model of basin hydrology*, Hydrol. Sci. Bull., 24, 43–69.
2. Beven, K. J., Wood, E. F., Sivapalan, M, (1988), *On hydrological heterogeneity – catchment morphology and catchment response*, J. Hydrol., 100, 353–375, 1988.
3. Desmet, P.J.J., Govers, G., (1996), *Comparison of routing algorithms for digital elevation models and their implications for predicting ephemeral gullies*, International Journal of Geographical Information Systems, 10, 311-331.
4. Desmet, P.J.J., Govers, G., (1997), *Two-dimensional modelling of the within-field variation in rill and gully geometry and location related to topography*, Catena, 29, 283-306.
5. Hutchinson, M. F. (1988), *Calculation of hydrologically sound digital elevation models*, Paper presented at Third International Symposium on Spatial Data Handling at Sydney, Australia.
6. Hutchinson, M. F., (1989), *A new procedure for gridding elevation and stream line data with automatic removal of spurious pits*, Journal of Hydrology, 106: 211–232.
7. Nico G., Rutigliano P. (2005), *Terrain modeling by kinematical GPS survey*, Natural Hazards and Earth System Sciences, nr. 5.
8. Guzzetti F., Tonelli G., (2004), *Information system on hydrological and geomorphological catastrophes in Italy (SICI): a tool for managing landslide and flood hazards*. Nat Hazards Earth Syst Sci 4(2):213–232.
9. Carbonneau Patrice E., Lane Stuart N., Bergeron N., (2006), *Feature based image processing methods aplied to bathymetric measurements from airborne remote sensing in fluvial environments*, Earth Surface Processes and landforms, vol.31.
10. Todica S., (2009), *Morfodinamica actual in zona de contact Obcinele Bucovinei-Podisul Sucevei*, Teza de doctorat, Cluj-Napoca.
11. Goodchild, M. F., D. M. Mark, (1987) The fractal nature of geographic phenomena. *Annals of Association of American Geographers*. 77 (2): 265-278.