Cent. Eur. J. Geosci. • 6(3) • 2014 • 363-372
DOI: 10.2478/s13533-012-0181-0

VERSITA

Central European Journal of **Geosciences**

Assessment of surface runoff depth changes in Sărățel River basin, Romania using GIS techniques

Research Article

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Received 04 October 2013; accepted 12 June 2014

Abstract: Sărățel River basin, which is located in Curvature Subcarpahian area, has been facing an obvious increase in frequency of hydrological risk phenomena, associated with torrential events, during the last years. This trend is highly related to the increase in frequency of the extreme climatic phenomena and to the land use changes. The present study is aimed to highlight the spatial and quantitative changes occurred in surface runoff depth in Sărățel catchment, between 1990-2006. This purpose was reached by estimating the surface runoff depth assignable to the average annual rainfall, by means of SCS-CN method, which was integrated into the GIS environment through the ArcCN-Runoff extension, for ArcGIS 10.1. In order to compute the surface runoff depth, by CN method, the land cover and the hydrological soil classes were introduced as vector (polygon data), while the curve number and the average annual rainfall were introduced as tables. After spatially modeling the surface runoff depth for the two years, the 1990 raster dataset was subtracted from the 2006 raster dataset, in order to highlight the changes in surface runoff depth.

Keywords: Sărățel • Curve Number • Runoff • Land use change

1. Introduction

The increase in frequency and intensity of hydric risk phenomena is highly connected to the extreme meteorological phenomena, such as torrential rains, caused by the lately climate changes. Floods and flooding are generally the most damaging natural hazards, in terms of social and economic impact [1]. Consequently, these phenomena became an important issue for the scientific research.

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Different GIS and remote sensing techniques were employed in order to perform different methods for assessing flood, flash-flood and surface runoff potential [2, 3]. The qualitative approaches of the surface runoff potential are mainly focused on the computation of the *Flash-Flood Potential Index* (FFPI). Many researchers focused on calculating and spatially modeling this index: Smith [4], Zaharia *et al.* [5], Prăvălie and Costache [6], Minea [7]. Other methods, such as the curve number (SCS-CN), concern the quantitative assumption of the surface runoff depth, based on a certain amount of rainfall. The SCS-CN method has widely been used in international studies by different authors: Kumar *et al.* [8], Mack [9], Scozzafava and Tallini [10], Xiaoyong and Min-Lang [11], Duncan *et al.* [12], Al-Hasan and Mattar [13], Mahmoud *et al.* [14] but also in Romanian studies by: Haidu *et al.* [15], Bilaşco [16], Minea [17], Gyory and Haidu [18],Domniţa [19], Costache [20], Elbialy *et al.* [21]. The deployment of the curve number method was performed by the Natural Resources Conservation Service (NRCS).

The SCS-CN hydrological model consists in a methodology for transforming a certain amount of rainfall for a certain period of time into surface runoff, taking into consideration the land-use and the hydrological soil classes [16].

Apart from this method, there are also other models used in different studies, such as: KINEROS [22], LISEM [23], TOPMODEL [19], RHEM (Rangeland Hydrology and Erosion Model) [24], NAM rainfall-runoff model [25], HEC-HMS [21, 26, 27], Mike 11 [28] which offer quantitative simulations of the surface runoff depth based on a certain amount of rainfall.

This study aims to highlight the changes in the surface runoff depth within Sărăţel river basin during 1990-2006 and to assess the influence of land use changes on this hydrological parameter. Numerous studies regarding the influence of land use changes on surface runoff were realized by researchers like: Garcia *et al.* [29], Haverkamp *et al.* [30], Hernandez-Guzman *et al.* [31], Descroix *et al.* [32], Costea [33], Costache and Fontanine [34]. As Sărăţel river basin is frequently affected by hydric risk phenomena - such as flash floods, mapping the areas having experienced an increase in the surface runoff potential is very important in order to adopt the necessary preventive measures, concerning especially the flash-floods.

2. Study area

Sărăţel river basin is located in the central south-eastern part of Romania (Figure 1). Sărăţel is a tributary of the Buzău River and flows through the Curvature Subcarpathian area. The surface of the river basin records approximately 190 km^2 and belongs to the category of basins having flash-floods risk [35].

The shape factor of the river basin is 0,46 (Table 1), according to the formula [36]:

$$R_c = \frac{4\pi \cdot F}{P^2} \qquad (1)$$

where R_c - shape factor, F - the surface of the river basin, P - the perimeter of the river basin, suggesting an almost circular shape of the basin, which is an important driving force of the flash-flood phenomena.

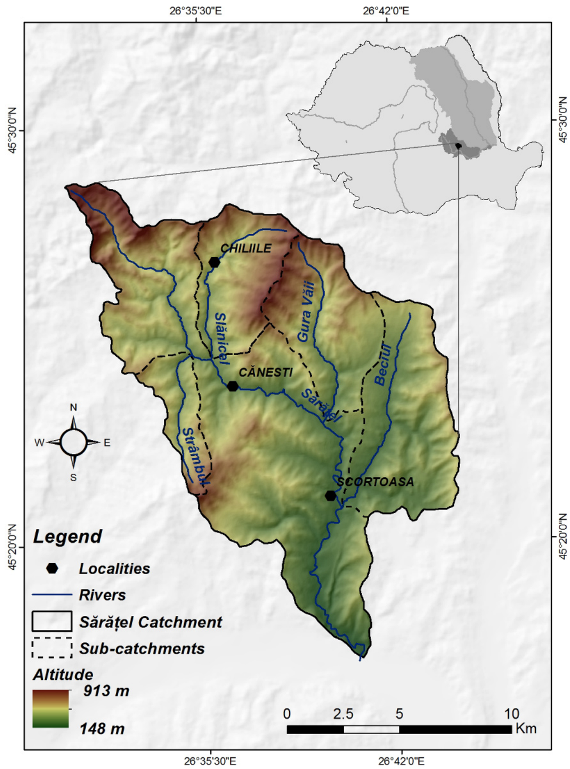

Figure 1. Study area location.

Other morphometric features of Sărăţel river basin and its tributaries are described in the Table 1. The elevation of the study area ranges from 148 m to 913 m (Figure 1), meanwhile high slopes (>15°), favorable to surface runoff, occur on almost 20% of the total study area.

The distribution of the average annual rainfall (1960 - 2013) ranges between 558 mm in the lower area of the river basin, at the confluence with Buzău River, and 725 mm on the highest hilly areas. The average annual rainfall was computed for the study area in GIS environment, totalizing 616 mm/year.

As far as the vegetation is concerned, the forest cover has a major hydrological role in regularizing the runoff within the basin, by means of rainfall interception [37]. The studied basin faces a shortage in forest cover (only 27%), having a high exposure to flash-floods. Regarding the pedological characteristics, 78% of the study area (Figure 3(d)) contains fine-textured soils, belonging to D hydrological class where the clay content is above 40%, while the sand content is below 50%, resulting a reduced saturated hydraulic conductivity, of 0.4 μm/s maximum [38]. By contrast, the other soil classes

Table 1. Morphometrical features of the Sărăţel River Catchment and its main sub-catchments.

River	Sub-catchment						Hydrographic network	
	Area	Perimeter	R_c (shape coefficient)	Altitude (m)			Length	Imed (river slope)
	(sq km)	(km)	$R_c = \frac{4\pi A}{P^2}$	med	max	min	(km)	(m/km)
Slănicel	21.1	19.7	0.68	538	811	302	8.6	45.7
Gura Văii	26	22.2	0.66	490	811	238	9.3	57
Beciul	34.9	28.96	0.52	348	587	193	10	22.8
Strâmbul	9.78	16.81	0.43	468	760	317	6.4	55
Sărăţel	188	72	0.46	415	913	148	34.6	30.2

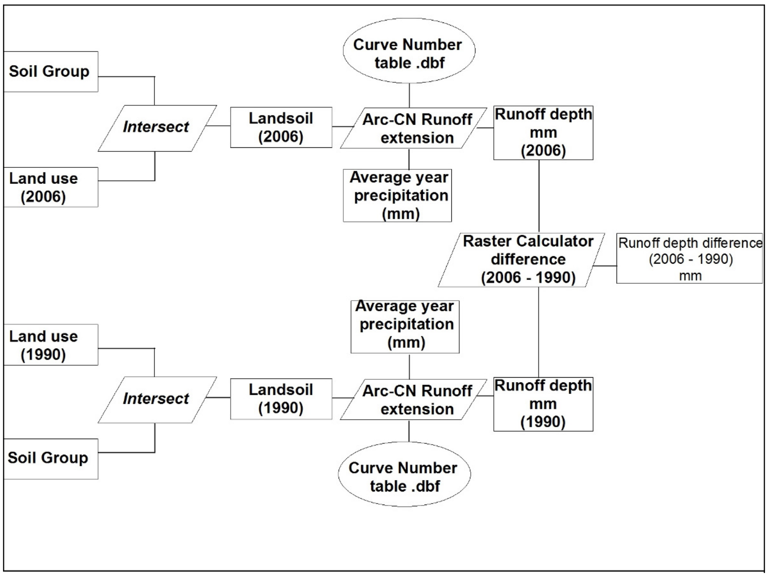

Figure 2. The working steps in estimating the surface runoff depth changes between 1990-2006.

have different characteristics: the A class contains approximately 10% clay and 90% sand and gravel, having a saturated hydraulic conductivity above 40 μm/s which favors the water infiltration [38]; the soils belonging to B class are composed of 10-20% clay and 50-90% sand, resulting a saturated hydraulic conductivity between 10 and 40 μm/s [38]; the C class soils are made of 20-40% clay and more than 50% sand and have a saturated hydraulic conductivity between 1 and 10 μm/s [38].

The fine-textured soils lead to a decrease in water infiltration, favoring the surface runoff [35]. These soils are included in the D group of soils, according to the classification by the hydrological characteristics [35].

3. Data and Methods

In order to assess the spatial changes of the annual average surface runoff depth between 1990-2006, the performed workflow included several steps, described in the Figure 2.

Firstly, the necessary data was generated to estimate the surface runoff depth for each of the two mentioned years.

The distribution of the annual average surface runoff depth within Sărăţel river basin was computed using the mathematical hydrological model SCS-CN (CN = Curve Number), created by the Natural Resources Conservation

Services (SUA). This method is based on the formula [16]:

$$Q = P - Is - I - E - n \quad (2)$$

where Q - depth of direct runoff, P - precipitation, Is - infiltration capacity, I - interception, E - evapotranspiration, n - other retentions of the precipitation. The CN method is based on the conventional representation of the maximum retention potential during rainfall [16], which is influenced by the type of land cover and the hydrological group of soil. Mathematically, the estimation of the surface runoff depth is based on the formula [39, 40]:

$$Q = \frac{(P - 0.2 \cdot S)^2}{P + 0.8 \cdot S} \quad (3)$$

where Q - depth of direct runoff (mm), P - precipitation (mm), S - the potential for water retention (mm). The potential for water retention is based on the curve number CN, according to this formula [41, 42]:

$$S = \frac{25400}{CN} - 254 \quad (4)$$

where CN - the curve number resulted from the intersection between land cover and hydrological group of soil.

The surface runoff depth for each of the two years was performed through the Curve Number method, by means ArcCN - Runoff extension [11] in ArcGIS 10.1. The following data was used:

- vector datasets: land covers for 1990 and 2006, taken from Corine Land Cover database [33] (Figure 3(a), (b)) and the soil type, taken from Romanian Soils digital Map, 1:200000 [44], grouped by their hydrological class [20] (Figure 3(d));

- numerical datasets: the average annual rainfall within the river basin (616.86 mm/year), extracted from the raster containing the spatial distribution of the average rainfall within the study area (Figure 3(c)). The spatial modeling of the rainfall within Sărăţel river basin was performed by the simple linear regression between the average annual rainfall recorded at the inner stations - as dependent variable and their absolute altitude - as independent variable. This analysis was based on average annual rainfall data between 1960 and 2012, belonging to 13 meteorological stations situated around the study area and provided by the National Meteorology Administration [45].

- table dataset for the curve number value according to each intersection between the hydrological class of soil and the type of land cover. The curve number records values ranging from 0 (for surfaces without water flow) and 100 (for surfaces with maximum surface runoff) [19].

The average surface runoff for the years 1990 (Figure 4(a)) and 2006 (Figure 4(b)) was firstly mapped on vector - polygon data. In order to calculate the difference between the two years, the polygon datasets were converted into raster datasets having 10 m resolution. By subtracting the raster for the year 1990 from that corresponding to the year 2006 (Figure 2), a new raster, representing the changes in the annual average surface runoff depth, was obtained.

The assessment of the relation between land use changes and the changes in the surface runoff depth was performed by spatially modeling the Markov Index and by intersecting its values with the map containing surface runoff depth changes (both in polygon format), through Intersect tool in ArcGIS 10.1.

Computing the Markov matrix required a preliminary step of coding each land cover type. Consequently, the 8 land cover classes for 1990 received codes ranging from 10 to 80, while those for 2006 received codes from 1 to 8 (Table 2).

The next step consisted in converting the resulted vector data - for 1990 and 2006 into raster data, having the correspondent codes as cell values. Finally, the Markov matrix (Table 3) was computed through cartographic algebra - Raster Calculator from ArcGIS 10.1 - by adding up the two rasters, according to the following formula:

$$LC_{1990} + LC_{2006} = M_{m(1990-2006)},$$

where LC_{1990} - land cover for 1990, LC_{2006} - land cover for 2006, $M_{m(1990-2006)}$ - Markov Matrix.

The resulted values of Mm(1990-2006) for Sărăţel basin, ranges from 11 to 88 (Table 3), so: the values containing two identical digits, such as 11, 22, 33 etc. suggests areas where the land cover remained the same through the study period, while all the other values denote a change to the direction indicated by the second digit of the cell number (Table 3).

4. Results and Discussion

By applying the described methodology, the values of the annual average surface runoff depth were spatially modeled within Sărăţel river basin (Figure 4(a) and (b)). The values recorded for the years 1990 and 2006 ranged

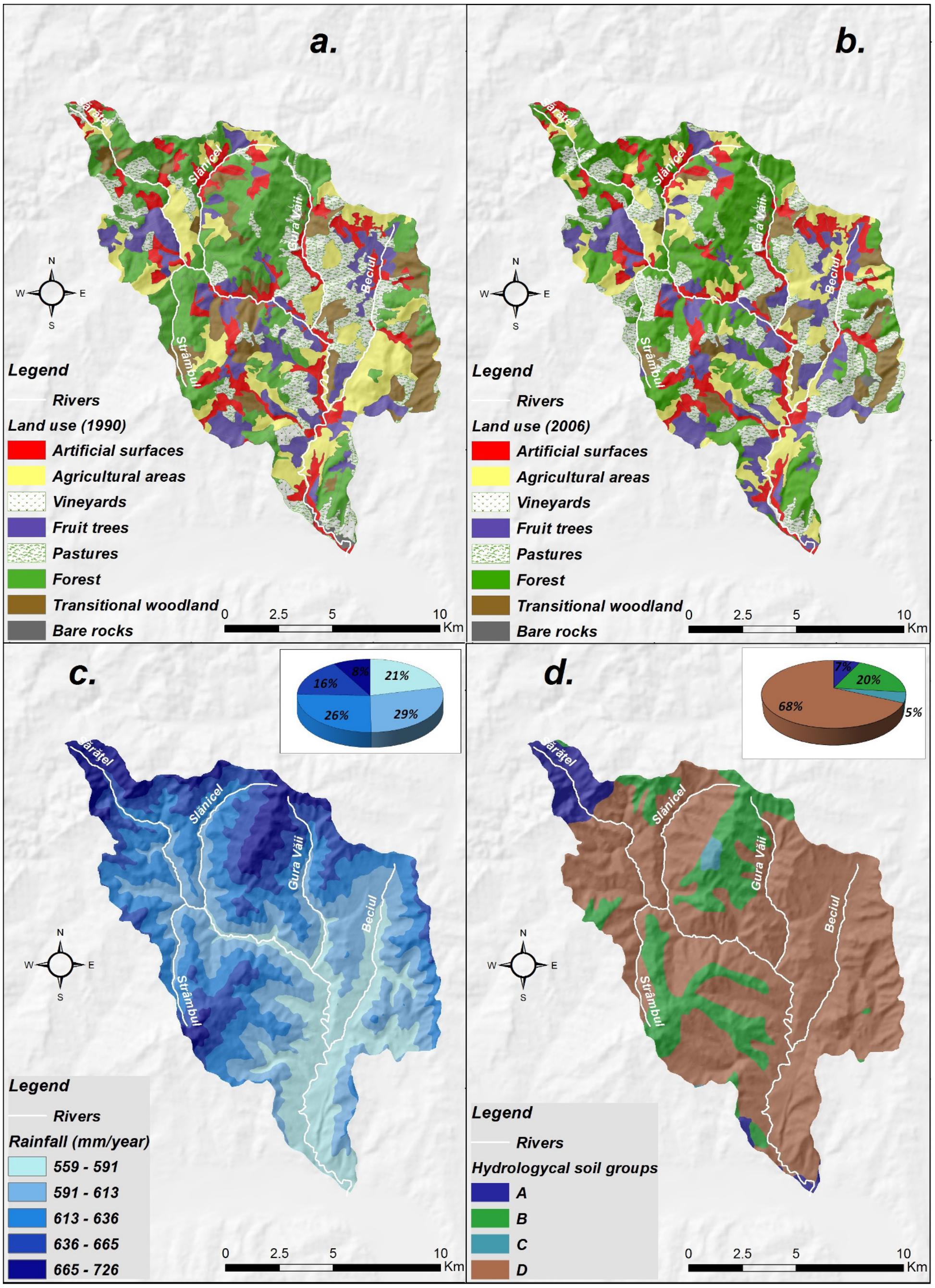

Figure 3. The factors considered for the computation of the surface runoff depth (a) land cover 1990; (b) land cover 2006; (c) annual average rainfall; (d) hydrological soil groups.

between 263 mm/year and 598 mm/year (Figure 4(a) and (b)). The lowest values occur, in both cases (1990 and 2006), in the northern part of the study area, at the contact area with the Carpathians and are caused, on the one hand by the high potential of water interception by the forest coverage and, on the other hand, by water retention due to the predominantly sandy soil texture. As in these areas the runoff represents 43-53% of the total rainfall, the risk

Table 2. The coding of the land cover (1990 and 2006) for computing Markov matrix.

1990		2006	
cod	Land cover/use	cod	Land cover/use
10	Artificial surfaces	1	Artificial surfaces
20	Agricultural areas	2	Agricultural areas
30	Vineyards	3	Vineyards
40	Fruit trees	4	Fruit trees
50	Pastures	5	Pastures
60	Forest	6	Forest
70	Transitional woddland	7	Transitional woddland
80	Bare rocks	8	Bare rocks

Table 3. Markov matrix - land cover change directions for 1990-2006 period.

2006	1	2	3	4	5	6	7	8
1990	Artificial surfaces	Agricultural areas	Vineyards	Fruit trees	Pastures	Forest	Transitional woodland	Bare rocks
10 Artificial surfaces	11 *2280* *Hectares*	12	13 *9* *Hectares*	14 *31* *Hectares*	15 *44* *Hectares*	16 *18* *Hectares*	17	18
20 Agricultural areas	21	22 *1005* *Hectares*	23 *50* *Hectares*	24 *89* *Hectares*	25 *105* *Hectares*	26 *2* *Hectares*	27	28
30 Vineyards	31 *3* *Hectares*	32	33 *2169* *Hectares*	34 *35* *Hectares*	35 *196* *Hectares*	36 *18* *Hectares*	37	38
40 Fruit trees	41 *8* *Hectares*	42	43 *206* *Hectares*	44 *2234* *Hectares*	45 *372* *Hectares*	46 *141* *Hectares*	47 *52* *Hectares*	48
50 Pastures	51 *37* *Hectares*	52	53 *253* *Hectares*	54 *110* *Hectares*	55 *1744* *Hectares*	56 *94* *Hectares*	57 *83* *Hectares*	58
60 Forest	61 *120* *Hectares*	62	63 *44* *Hectares*	64 *428* *Hectares*	65 *120* *Hectares*	66 *4709* *Hectares*	67	68
70 Transitional woodland	71 *8* *Hectares*	72	73 *57* *Hectares*	74 *240* *Hectares*	75 *277* *Hectares*	76 *339* *Hectares*	77 *1182* *Hectares*	78
80 Bare rocks	81	82	83	84	85	86	87	88 *28* *Hectares*

surface runoff is highly decreased.

The most exposed to surface runoff areas are built up areas, pastures and river valleys, where the Curve Number frequently exceeds the value of 90. The Saratel basin contains such areas, which favor a water flow of 571 – 598 mm/year, representing 92% – 97% of the total annual rainfall. For the years 1990 and 2006, the areas with high values of the annual average surface runoff depth overlap the main river valleys, respectively Sărăţel, Slănicel, Beciul (Figure 4(a) and (b)), but also in the north-eastern part of the study area. These areas are the most vulnerable to hydric phenomena, such as flash-floods.

At the same time, due to land cover changes between 1990

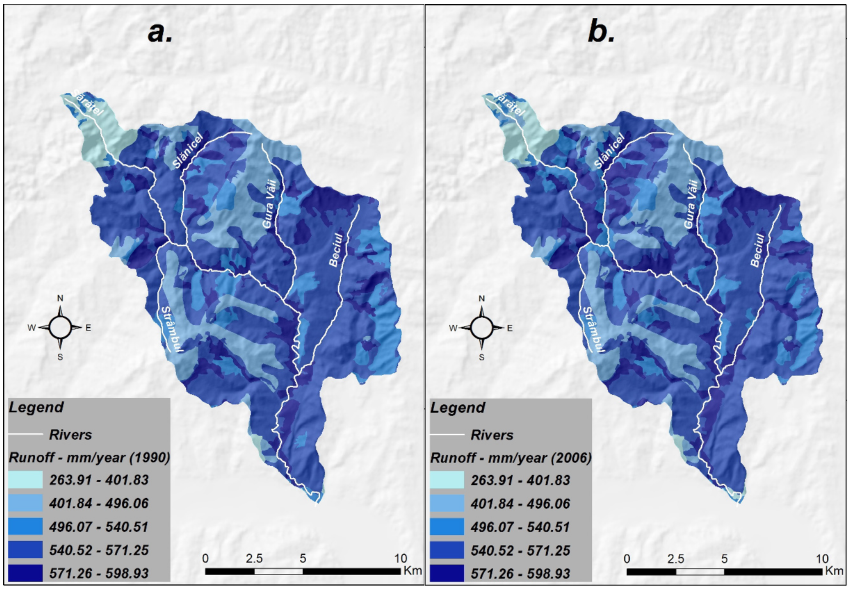

Figure 4. The spatial distribution of the average surface runoff depth within Sărățel river basin (a) 1990; (b) 2006).

and 2006, important spatial and quantitative changes of the surface runoff depth occurred too. The surface runoff depth values remained stationary for almost 74% of the study area (Figure 5). Thereby, approximately one quarter of the study area suffered from changes in the surface runoff depth between 1990 and 2006. The maximum decrease in the surface runoff depth exceeds 233 mm/year, while the maximum increase in the surface runoff depth reaches only 150 mm/year.

On the whole, the values of the surface runoff depth decreased by 2270 hectares, respectively 13% of the study area (Figure 5). The decrease in the surface runoff depth given by rainfall is caused by the changes in land use consisting in afforestations.

The growth of the annual average surface runoff depth also occurred on approximately 13% of the study area - 2680 hectares. The widest area where the surface runoff depth increased is situated along Sărăţel River valley (Figure 6), which is the only area where the areas having faced an increase in the surface runoff depth - by almost 1250 ha - considerably exceeded the areas where this parameter decreased - by almost 200 ha (Figure 6).

The same dynamics was specific for Beciul sub-basin, where surface runoff depth increased by almost 621,9 hectares (Figure 6), which is approximately 18% of the total area (Table 4), meanwhile the decrease affected only 371 hectares (Figure 6) - approximately 11% of the sub-basin surface (Table 4).

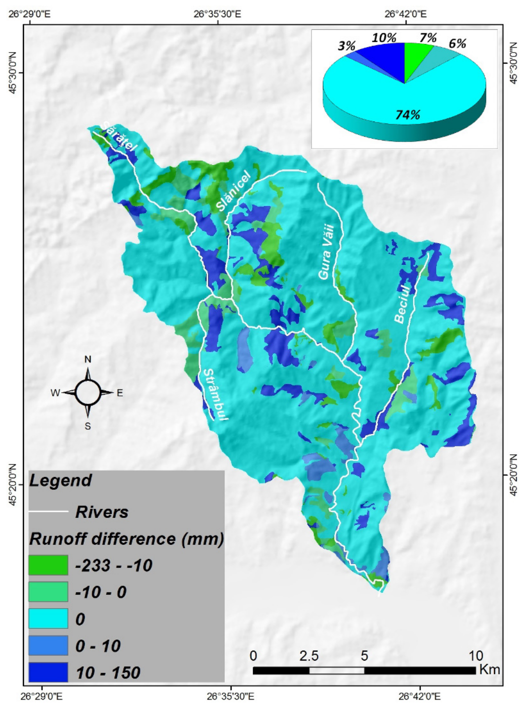

Figure 5. The changes of the annual average surface runoff depth values in Sărățel river basin (1990 - 2006).

Table 4. The weight of the surface runoff depth changes by classes of values within Sărățel river catchment and its river sub-catchment.

Sub-catchments	Area (sq km)	Weight (%) 1	2	3	4	5
		-233 - -10 mm/year	-10 - 0 mm/year	0 mm/year	0 - 10 mm/year	10 - 150 mm/year
Slănicel	21.1	14	8	63	1	14
Gura Văii	26	2	4	91	0	3
Beciul	34.9	5	6	71	1	17
Strâmbul	9.78	1	24	62	0	13
Sărăţel	188	7	6	74	3	10

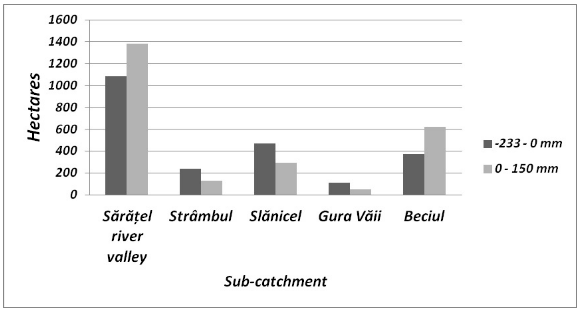

Figure 6. The extent of the areas where surface runoff depth changes occurred within the river sub-basins of the study area (1990, 2006).

On the contrary, the sub-basins Gura Văii, Slănicel and Strâmbul, the decreases affected larger areas than increases (Figure 6). Within Slănicel river sub-basin, the surface runoff depth rose by 291 hectares - approximately 15% of its area, while the decrease occurred on almost 470 hectares, respectively 22% of the river sub-basin area (Table 4). A similar situation corresponds to Strâmbul River sub-basin, where the surface runoff depth increased by 125 hectares (Figure 6) or 13% of its area, meanwhile the decrease affected 237 hectares (Figure 6)- 25% of its area (Table 4).

Consequently, the risk of flash flood occurrence and downstream propagation is enhanced by the presence, along the main river valley, of the areas having a high potential to transform most of the rainfall into surface runoff. This risk is highly strengthened as the most extended areas were affected by an increase in surface runoff depth between 1990 and 2006.

The flash-flood phenomena mostly affect the localities situated along the river valley, such as Căneşti and Scorţoasa (Figure 1). The torrential character of Sărăţel river valley, proven by the active runoff - which exceeds 90% of the rainfall (Figure 4(a) and (b)) - is also statistically confirmed by the difference between the multiannual average discharge and the values of water discharge with reduced probability of occurrence [46].

Thereby, the multiannual average discharge on the cross-section on Sărăţel River, near Scorţoasa locality, was of 0,232 m^3/s, meanwhile other values for different probabilities of occurrence were: 130 m^3/s for a probability of 10% (approximately 560 times greater than the multiannual average discharge); 175 m^3/s for a probability of 5% (approximately 732 times greater than the multiannual average discharge); 246 m^3/s for a probability of 2% (approximately 1060 times greater than the multiannual average discharge); 310 m^3/s for a probability of 1% (approximately 1336 times greater than the multiannual average discharge) [46]. According to the overlapping between the type of land use conversions (described by the Markov Index), and the changes occurred in surface runoff depth, the deforestations and the transitions to pastures had the most important impact (70%) on the growth of the surface runoff depth (0-150 mm).

5. Conclusions

Sărăţel river basin, located in a dynamic area regarding natural landscape, was affected by important changes in the annual average surface runoff depth between 1990 and 2006 due to the changes in land use.

The CN method, applied by Arc-CN Runoff extension in ArcGIS 10.1 showed its efficiency for the present study, as the computation and spatial modeling of the surface runoff depth managed to reveal the most vulnerable areas, where the exposure to hydrological risks is enhanced by the sharp increase in the surface runoff depth. Consequently, the present study highlighted the efficiency of the CN method in analyzing dynamic processes, too.

The computation of the differences between the surface runoff depth for 1990 and 2006 demonstrated that the values of the analyzed parameter increased especially along Sărăţel river valley. This caused the increase in the flash-floods risk and, consequently, the increase in the vulnerability of the main localities found along the Sărăţel River.

Acknowledgements

This paper has been financially supported within the project entitled "SOCERT. Knowledge society, dynamism through research", contract number POSDRU/159/1.5/S/132406. This project is co-financed by European Social Fund through Sectoral Operational Programme for Human Resources Development 2007-2013. Investing in people!

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