ESTIMATING MULTIANNUAL AVERAGE RUNOFF DEPTH IN THE MIDDLE AND UPPER SECTORS OF BUZĂU RIVER BASIN

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ABSTRACT:
The middle and upper sectors of Buzău river basin are located within an area highly exposed to flash floods. Thereby, studying surface runoff on different areas is very important. In this study, the average multiannual runoff depth was determined and spatially modelled by Curve Number method adjusted with slope. Generally, surface runoff values spatial distribution is correlated with precipitation amount. Also, surface coefficient was computed for the study area, due to its valuable information of the way that surface runoff occurs on slopes, during torrential rainfall. The results concluded that the Subcarpathian area between Buzău and Slănic river valleys is the most prone to torrential associated phenomena.

Key-words: *Curve Number, Slope, Buzău catchment, Runoff, Runoff coefficient.*

1.INTRODUCTION

The late climate global changes and anthropogenic disturbance of the environment also caused hydrologic phenomena changes (IPCC, 2007), which are mainly related to surface runoff occurrence. An increased number of mountainous and hilly areas is affected of torrential surface runoff, which cause flash floods and floods, natural phenomena that bring the most significant material damage and human life loss. Consequently, there many studies in the international specialty literature, also in Romanian literature, that are focused on specific methods of modelling rainfall - runoff process (Costache, 2014). One of the most popular methods used for estimating runoff depth from a given precipitation amount is the mathematical Curve Number, applied by several researchers : Kumar, Tiwart and Pal (1991), Haidu, Crăciun and Bilașco (2007), Bilaşco (2008), Minea (2011), Gyori and Haidu (2011), Domnița (2012), Duncan et al (2013).

Though, the main deficiency of this method is that it does not consider slope (Crăciun et al, 2009), a factor with a decisive influence on surface runoff occurrence. Another necessity of this method is to consider the average precipitation value for extended areas.

The aim of this study is to estimate runoff depth spatial variability in the middle and upper sectors of Buzău river basin, by Curve Number method calibrated with slope values. Also, in order to obtain a more precise average multiannual runoff depth, in terms of spatial distribution, the average multiannual precipitation values were integrated in the SCS-CN formula.

2.STUDY AREA

The middle and upper sectors of Buzău river basin are located in the central south-eastern part of Romania. The area surface is of 3674 km^2, 68% of the total Buzău river basin area. The study area is entirely overlain to the Curvature Carpathian and

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Subcarpathian areas, to altitudes between 114 and 1915 m. The most important sub-basins are Bâsca, Bâsca Chiojdului, Siriul Mare, Nișcov, Bălăneasa, Sărățel, Slănic and Câlnău (**Fig. 1**).

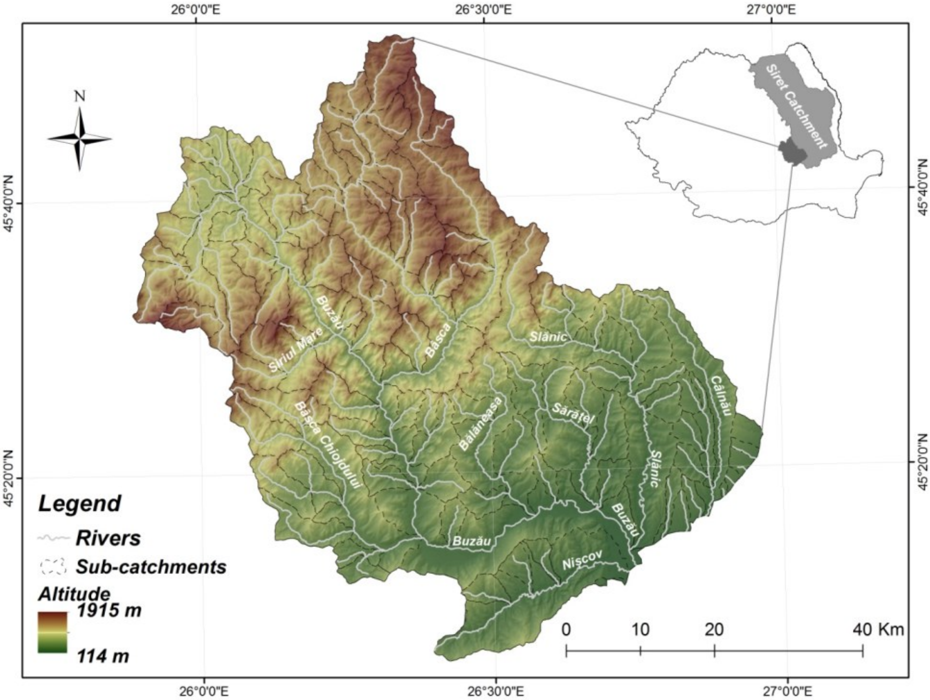

Fig. 1 Study area location.

Specific properties like area and shape (Rc) of the river basin influence the whole study area. Siriul Mare sub-catchment records the highest torrential character due to its low surface, under 100 km^2 (Drobot, 2008), and due to shape factor near 0.8 (**Table 1**) which indicates its circularity. The average slope of Siriul Mare, 33%, indicates a high potential for surface runoff and consequently for flash floods occurrence (**Table 1**).

From the morphometric point of view, one of the most important factors that influence surface runoff is slope (Costache & Pravalie, 2013). Its values range between 0.1% and 87.6% (**Fig. 3a**), and its average value is 21%. Precipitation is the main factors that generates surface runoff. The precipitation values within the study area, between 1970 – 2010, recorded 520 - 961 mm/year (**Fig. 3b**). The lowest precipitation values occur in hilly areas form the south-eastern part of the study area (**Fig. 3b**), meanwhile the highest values are recorded in the north-western part.

Land cover is another factor that influences surface runoff caused by precipitation, due to differences between roughness coefficient of each land cover type. The study is 57% covered by forest vegetation (Corine Land Cover, 2006), which has major role in controlling hydrologic phenomena (Arghiriade, 1977). In terms of pedologic cover, the hydrologic soil group B is mostly found in the mountainous area, meanwhile soil group C is predominant on hilly areas. Soils from D hydrologic soil group, on 10% of the total study area, cause a decreased potential for water infiltration and implicitly favors surface runoff.

Table 1. Morphometrical features of the Buzău River basin and its main sub-catchments in the upper and midle sector.

River	Sub-catchment						Hydrografic network	
	Area	Perimeter	Rc (shape coefficient)	Altitude (m)			Length	Imed (river slope)
	(sq km)	(km)	Rc = 4πA/P^2	med	max	min	(km)	(m/km)
Bâsca	783	148	0.45	1120	1769	387	79	14
Bâsca Chiojdului	340	97	0.45	658	1449	242	41	27
Bălăneasa	189	74	0.43	517	1167	169	33	21
Câlnău	172	85	0.30	369	862	163	41	13
Nișcov	221	78	0.46	332	727	117	38	10
Siriul Mare	84	39	0.69	1052	1647	624	19	33
Sărățel	189	72	0.46	428	913	147	35	22
Slănic	472	140	0.30	577	1346	119	72	16

3. METHODOLOGY

In order to estimate average multiannual runoff depth in the upper and middle sectors of Buzău river basin, the Curve Number method calibrated with slope was used. The SCS-CN method for estimating surface runoff is based on the retention potential (S) of a given surface depending on the land cover type hydrological soil group. water retention by various surfaces is calculated by the Curve Number index (CN). The mathematical relations between Curve Number and water retention potential are :

$$CN = \frac{25400}{S + 254} \ (1) \Rightarrow S = \frac{25400}{CN} - 254 \ (2),$$

where: CN – Curve Number and S- maximum retention potential (mm).

According to the equation, the estimation of maximum water retention capacity does not consider slope, which is a fundamental factor in regularizing surface runoff. In order to adjust slope to the SCS-CN formula, the following equation was used:

$$CN_{2\alpha} = CN_2 * \frac{322.79 + 15.63 * \alpha}{\alpha + 323.52}(\alpha + 323.52)$$ (3) (Huang et al, 2006), where:

$CN_{2\alpha}$ – the value of the curve number adjusted with the slope; CN_2 – SCS-CN value for a soil with medium antecedent humidity and α – slope (%).

The estimation of the spatial variation of average multiannual runoff depth for the study area was performed according to the workflow described in **Fig. 2**.

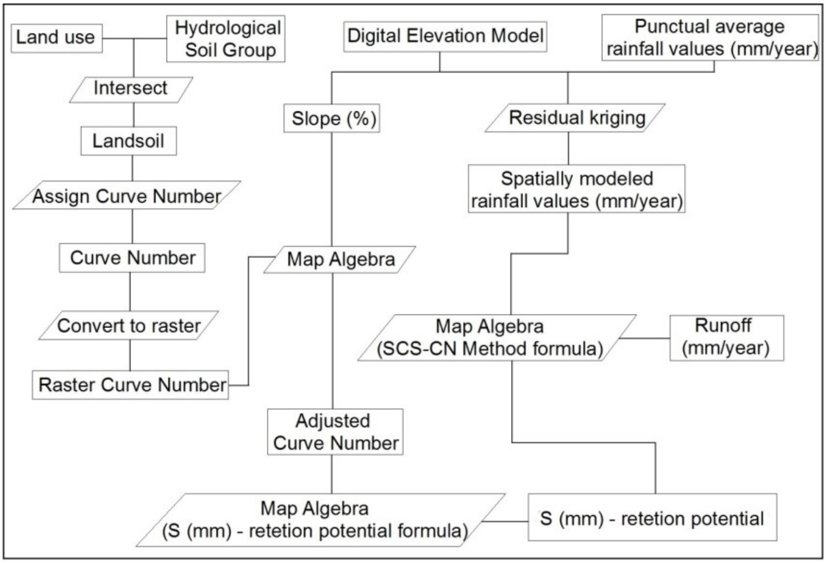

Fig. 2 Runoff depth estimation workflow.

Firstly, land use polygons (Corine Land Cover, 2006) were intersected overlapped with the hydrological soil groups in GIS environment. Each intersection surface was given a Curve Number, according to the land cover type and the hydrological soil group (**Fig. 3c**). Generally, the Curve Number ranges between 0 and 100. In the study area, the Curve Number values are between 0 and 94 (**Fig. 3c**). The polygon resulted from the intersection between the two thematic layers was converted from shape file format to raster format with 20 m cell size, according to the field which contains the Curve Number values. Secondly, slope values (%) was obtained from the Digital Elevation Model, at a 20 m cell size (**Fig. 3a**).

Once the two raster datasets obtained, respectively Curve Number index and slope, these were integrated in the final formula **(3)**, from which the raster corresponding to the CN values adjusted with slope was derived (**Fig. 3d**).

The following step of the workflow was to apply the formula **(2)** by cartographic algebra in ArcGIS 10.2, to obtain a raster with the maximum interception capacity (S), where CN values from formula **(2)** were replaced by $CN_{2\alpha}$ values. Thereby, S (mm) values were spatially modeled according to slope values.

The equation for estimating runoff depth on a certain surface by SCS-CN method is:

$$Q = \frac{(P - 0.2 * S)^2}{P + 0.8 * S}$$ (4) (Ponce & Hawkins, 1996), where :

Q – surface runoff depth (mm);
P – average multiannual rainfall (mm);
S – maximum retention potential (mm).

The average multiannual precipitation distribution within the study area is the last element which must be computed in order to apply the equation **(4)**. This parameter was obtained through the Residual Kriging interpolation method (Dumitrescu, 2012). This geostatistical method allows the spatial modeling of precipitation values based on the dependency relation of regression between the precipitation amount and the corresponding meteorological stations altitude.

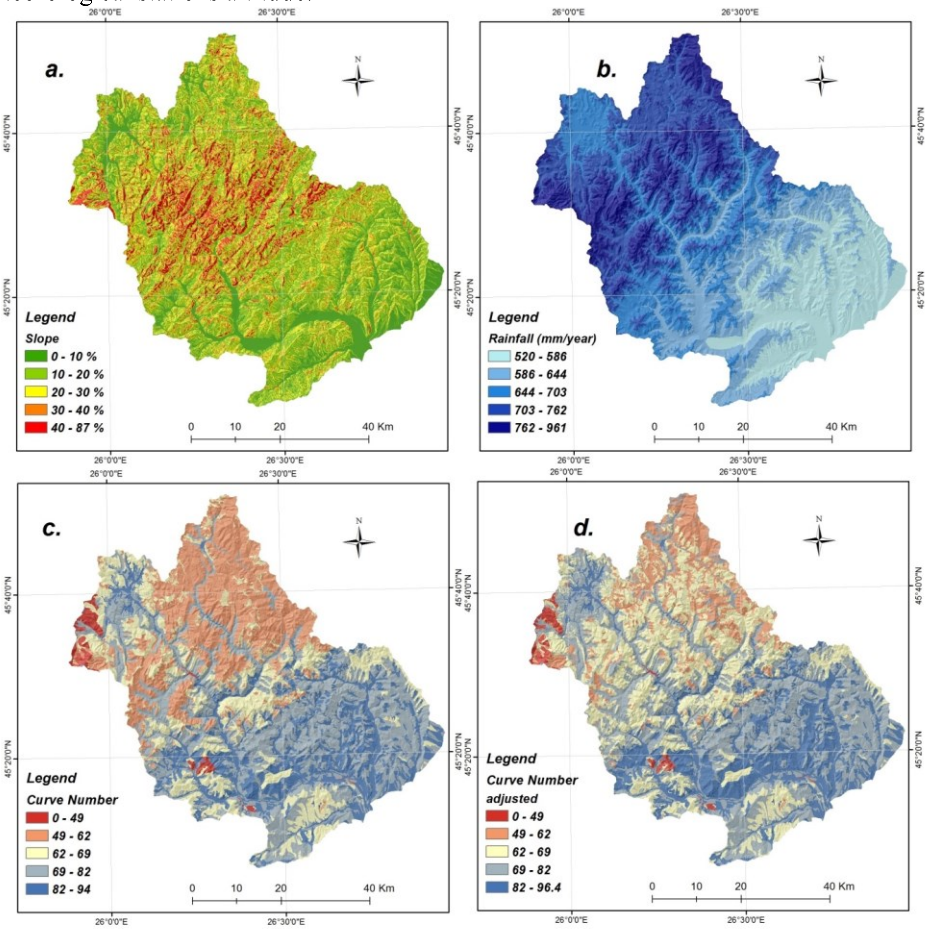

Fig. 3 The factors considered for calculating the average multiannual runoff depth (a. slope; b. rainfall; c. Curve Number; d. adjusted Curve Number).

In this study, average multiannual precipitation and altitude values from 20 meteorological stations were considered for the period between 1961 - 2000 (Clima României, 2008). By applying linear regression (**Fig. 4**) between precipitation, as the dependant variable, and the altitude as the explanatory variable, the determination coefficient R^2 is 0.76, meanwhile correlation coefficient (r) is 0.87. The R^2 value demonstrates a relative high dependency between precipitation and meteorological stations altitude.

Furthermore, cartographical algebra was used in order to spatially model average multiannual precipitation, by the regression equation : $y = 0.2175 * x + 524.61$**(5)**, where y is the theoretical values for precipitation within for the study area, meanwhile x is replaced the Digital Elevation Model. The raster containing the theoretical distribution of precipitation values was gathered with the raster obtained from the interpolation of the residual values for each meteorological station, which were obtained by subtracting the theoretical values from the measured values.

Hence, the raster containing the real values of precipitation within the upper and middle sectors of Buzău river basin were obtained (**Fig. 3.b**). This raster was included in equation **(4)** beside the raster corresponding to the maximum water retention capacity (S), in order to obtain the average multiannual runoff depth.

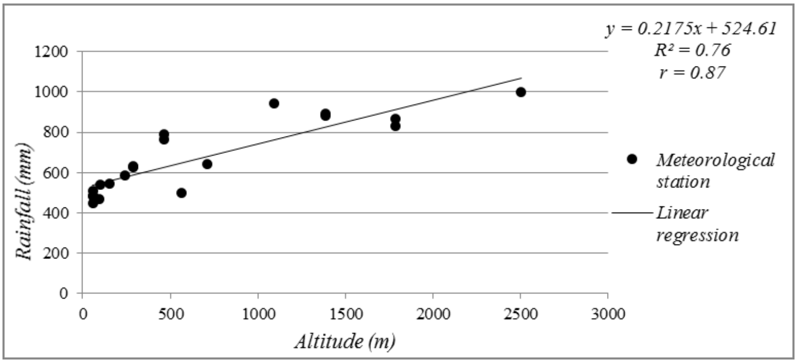

Fig. 4 The correlation between the rainfall values and meteorological stations altitude.

4. RESULTS

By applying the methodology described above, the runoff depth values were calculated for the upper and middle sectors of Buzău river basin between 1961 – 2000 (**Fig. 5**). The values of this parameter range between 306 and 910 mm. The lowest average multiannual runoff depth values are recorded in lower altitude areas, at the output of Buzău river from Subcarpathian area, where precipitation values are also lower and slope values almost 0 %. These areas, where runoff depth values are under 500mm/year, occur on almost 17% of upper and middle sectors of Buzău river basin (**Fig. 5**). Average multiannual runoff depth values between 500 – 575 mm/year (**Fig. 4**) are mainly recorded in the Subcarpahtian area, where average multiannual precipitation values reach 650 mm/an (**Fig. 3b**).

Runoff depth values under 575 mm/year are also recorded in the mountainous area where average multiannual precipitation values exceed 900 mm/year (**Fig. 3b**), due to low slopes and forest coverage over the hydrological soil group A. Surfaces with runoff depth values between 500 – 575 mm/year represent almost 37% of the study area. Another runoff depth class of values ranges between 575 – 650 mm/year and is the most representative, totaling 40% of the study area. These values occur mainly in the mountainous and higher hilly areas (**Fig. 5**).

The highest runoff depth values, exceeding 650 mm/year are recorded on almost 7% of the study area. The maximum recoded value is 910 mm/year in the mountainous area, respectively in Siriul Mare river basin and the north-western extremity of Bâsca Chiojdului river basin (**Fig. 5**).

Highlighting surface runoff occurrence on different areas can be performed through runoff coefficient, which is the ratio between runoff depth and precipitation values on a given surface at the same time. In this case, the average multiannual surface runoff coefficient was computed by the following formula:

$$C = \frac{Q(mm)}{P(mm)} \text{ (5), where:}$$

C – runoff coefficient;
Q – runoff (mm);
P – rainfall (mm).

By applying formula **(5)** in GIS environment, this parameter was spatially modeled within the study area (**Fig. 6**).

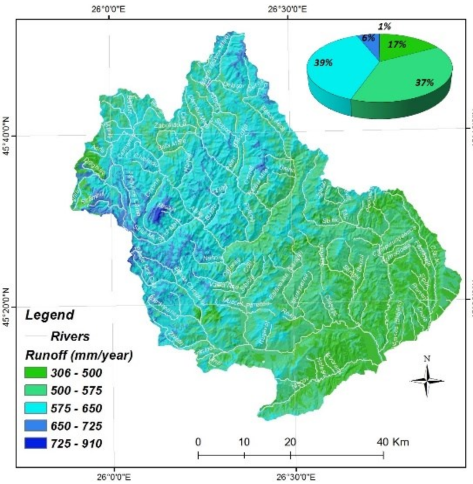

Fig. 5 Average runoff depth values within upper and middle sectors of Buzău Catchment (1960 -2000).

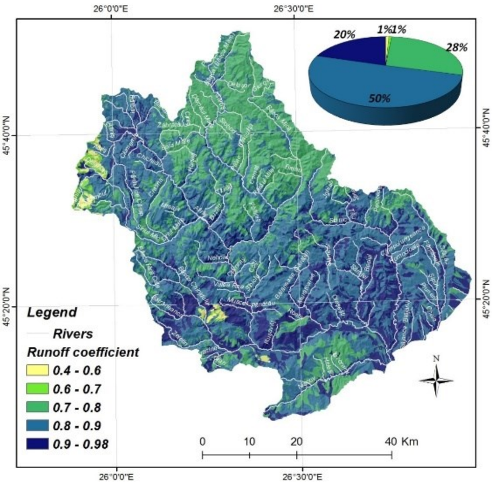

Fig. 6 Runoff coefficient within upper and midlle sector of Buzău Catchment (1960 - 2000).

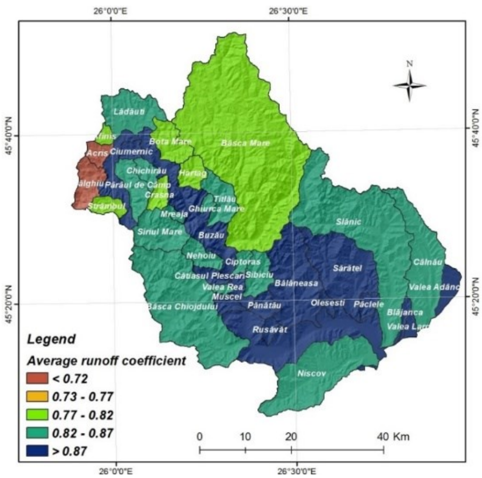

Fig. 7 The average values of runoff coeficient within the sub-catchments of upper and midlle sector of Buzau Catchment.

Within the upper and middle sectors of Buzău river basin, runoff coefficient values range between 0.4 and 0.98. values under 0.7 are recorded on only 2% of the study area, generally on forested areas with low slope values, which allow at most 70% of surface runoff from precipitation. This areas occur sporadically in Bâsca Chiojdului river basin depressions (**Fig. 6**) and in the north-western part of the study area. Runoff coefficient values between 0.7 and 0.8 occur mainly within the mountainous area of Bâsca river basin (**Fig. 6**), on a third part of the total upper and middle sectors of Buzău river basin. Over 70% of the study are is characterized by high and very high surface coefficient values, which accentuates the torrential character of the study area.

The highest values that demonstrate that almost 100% from all the precipitation quantity is integrated in the surface runoff flows. These areas are characterized by a highly degree of deforestation, with high slope values, mainly in the Subcarpahtian area. The highest average runoff coefficient values, over 0.87, are concentrated in the central part of the Subcarpahtian area (**Fig. 7**). Thereby, Bălăneasa, Pănătău, Rușăvăț, Sărățel and Pâcleleriver basins are the most exposed to torrential phenomena like flash floods, due to higher water quantity which flows on the bare land surfaces.

This assessment is confirmed by statistical data which prove that debits with 1% of excedence probability is almost 1336 times the average multiannual debit from a control section on Sărățel river (310 m^3/s comparing to 0.232 m^3/s) (Costache et al, 2014).

5. CONCLUSIONS

The SCS-CN method calibrated with varied slope values, lead to a better accuracy of the results when estimating runoff depth values from a given precipitation quantity.

Through the SCS-CN method calibrated with slope, for the upper and middle sector of Buzău river basin, maximum runoff depth values exceed the values obtained from the classical formula, due to higher Curve Number values by adjusting with slope than the common Curve Number index values.

Also, by calculating surface runoff coefficient, areas where water flow reaches 100% were spatially highlighted within the study area. This method is useful for management activities in different economical fields, given the high susceptibility for torrential phenomena and flash floods which cause significant damage.

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