Babeş-Bolyai University Cluj-Napoca

Faculty of Geography

Doctoral School of Geography

DOCTORAL THESIS

-Summary-

Maximum runoff discharge in ungauged small river basins. Study cases from Mureş river basin.

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1. Introduction. General aspects.

1.1. Scope and objectives.

The aim of the research initiated by me was to identify effective methods for determining the maximum flows on small, unmonitored, and ungauged watercourses, without measurements, in order to facilitate a forecast of the maximum discharge from these small hydrographic basins, with sometimes undesirable effects on human communities. Achieving this goal involved going through the following stages of research:

a) Identification of natural and anthropogenic factors that influence leakage and maximum flow rates in small basins;
b) Identification of the type of correlations and determinations between morphology, morphometry, type of land use and maximum run-off values;
c) Analysis of the influence of the vegetation coverage coefficient and soil types in generating the maximum discharge in small basins;
d) Analysis of the role of precipitation in the formation of maximum runoff and occurrence of floods in small hydrographic basins;
e) Analysis of the role of anthropogenic factors on the formation of leakage;
f) Analysis on case studies (51 small, ungauged hydrographic basins, without measurements) of the conditional factors by the Romanian rational method (RNS) and the American method (SCS-CN).

1.2. The importance of maximum runoff discharge calculation in small ungaged river basins

The importance of small basins without hydrological measurements results from their close connection with the genetic factors of maximum runoff and in particular with the conditional factors of leakage that refer to the aspects characteristic of the surfaces, to the basin facies.

Thus, changes in land use, soil degradation processes, accelerated erosion of slopes, natural deforestation phenomena, illegal deforestation, shaved felling of forests, afforestation works, plantations, urbanization processes, road constructions, houses, industrial platforms, concrete surfaces, can majorly influence small watersheds.

A continuous and reliable estimate, scientifically based on correct mathematical calculations, is an important factor in the sustainable management of water resources. The analysis of the maximum leakage is also important in the design of critical engineering structures such as communication paths, drainage systems, impoundments, regularizations or storage reservoirs.

2. The current stage of national and international research regarding the maximum runoff in small ungaged river basins

2.1. National and international literature review

The calculation of the maximum leakage in the small hydrographic basins in Romania is determined using various research approaches, such as the rational standard (rational national standard- RNS) method, the regionalization or synthesis methodology, Q200 and the methodology for calculating the hourly rain (Diaconu and Miță, 1997; Voda et al., 2018; Voda et al., 2019). The methodologies for calculating the maximum runoff require a correct assessment of the typology of soils, vegetation and land cover.

As the National Institute of Hydrology and Water Management (INHGA) increasingly recommends the use of the rational method for calculating the maximum runoff of small river basins, in-depth research of its impact is required in Romania, where the SCS-CN methodology is still a pioneering approach in this process (Zaharia et al., 2017; Șarpe and Vodă, 2017). According to the OMMD (2008), Grimaldi et al. (2012, 2013, 2015) the rational method had to be continuously updated taking into account new technological trends, which generated a significantly improved methodology for calculating and evaluating the maximum runoff in undeveloped small watersheds (Ditthakit et al., 2021).

2.2. Maximum runoff discharge in small ungaged river basins scientific literature approach

The continuous evaluation and observation of the physico-geographical and anthropogenic parameters in the small hydrographic basins of the Mures River, integrates the present research into a wider integrated regional system, which allows us to better understand the exchanges of matter, information and energy in the hydrological subsystems. We have selected 51 small hydrographic basins of the Mures River because they accumulate hydrological data representative of the researches carried out. In addition, previous studies suggest that small river basin models are a good predictor of the evolution of the parameters involved in the calculation of the maximum runoff (Irimuș et al., 2015; Voda et al., 2018). Deitch et al. (2016) stressed the importance of water resource policies for ecological river basin management. From a local scale to a regional and national scale, sustainable development strategies must take into account changes in land use over time and clearly indicate relevant solutions for the future.

In this paper, the SCS CN- RNS methodology for comparing the lag time was aimed at identifying the best predictions of the evolution of the maximum runoff of unmonitored watersheds and providing solutions for integrated watershed management without hydrological measurements (Ditthakit et al., 2021; Psomiadis et al., 2020). Both methods required an assessment of the use of land, vegetation and soil using available satellite imagery data. The novelty brought about by the research in this paper consists of an integrated cross-analysis of two different methodologies (SCS-CN and rational method) to improve the assessment of the interaction between precipitation and drainage for small unmonitored watersheds.

3. Research methodology and data used

The research methodology was based on the collection and realization of the database resulting from the laboratory calculations, of the field activities, on the processing and interpretation of the 1122 parameters (Annexes) of the hydrographic basins analyzed, in addition to the hydrological background data from the standard hydrometric networks and of the pluviometric fund used to control the results obtained in the calculation of the maximum flows for all the 51 case studies within the Mures river basin.

The activities carried out in order to achieve the proposed objectives regarding the maximum discharge, the calculation of the maximum flows in the small ungauged basins, included information, research and documentation activities, field activities, processing activities, interpretation, analysis and synthesis of the results.

The field activities carried out during the five years of research (in the period 2016-2021) allowed the collection of data through direct observations, measurements, unstructured interviews with locals in order to obtain information on the dynamics of the environmental factors that determine and condition the maximum leakage, the circulation of water on the slopes and in the riverbed within the 51 hydrographic basins analyzed.

4. The analisys of natural and antrophic factors that influence maximum discharge in small ungauged river basins

The geographical position, the relief, the geological structure, the soils, the vegetation, the climatic conditions, the degree of land use influence the hydrological phenomena and processes, constituting, together with the morphometric characteristics of the studied hydrographic basins, the database necessary for the objective analysis and the calculation of the maximum runoff.

Being developed on an area of 27890 km^2, between 20°11' west longitude and 25°44' east longitude, 47°08' north latitude and 45°14' south latitude, the Mures hydrographic basin is positioned in the center and west of Romania, having the Eastern Carpathians in the eastern part and in the north, the Southern Carpathians in the south, the Western Carpathians in the north and west, respectively the Someșan Plateau in the north. The length of the main water collector in the basin, the Mures River, is 761 km, but together with all the tributaries that contribute to the drainage, it totals 10800 km of watercourses with an average density of 0,39 km/km^2 relative to the basin surface.

The variety of landforms in the Mures River basin influences through their distribution the manifestation of climatic, pedographic, biogeographical and hydrographic parameters in the 51 small basins not monitored hydrologically, analyzed in this thesis.

4.1. The morphology and morphometry of the Mureş hydrographic basin.

The hydrographic basins located at high altitudes such as Catariga (1298 m), Valea Largă (1198 m), Şugău (1030 m), Ocolișel_1.03 (1210 m), Feernic (900 m), receive a higher amount of precipitation compared to those at lower altitudes, presenting a lower evaporation rate and implicitly a richer drainage, thus noting the influence of altitude on the hydrological elements.

The proportionality of the maximum leakage in relation to its genetic factors is well expressed in the Şomoșd, Silvașu, Borzești hydrographic basins, which have a vertical zonality of the physico-geographical elements.

Small valleys favor the rapid increase of water levels in rivers shortly after the onset of precipitation, their variations being faithfully reflected in the increases in the amounts of water in the river. The role of regularizing the runoff is represented only by the wide valleys, encountered especially in large watersheds. However, relatively wide valleys can be found in small fan-shaped watersheds, such as Roșia Poieni (Figure 6). These fan forms of small basins influence the way of concentration of the waters, favoring the drainage.

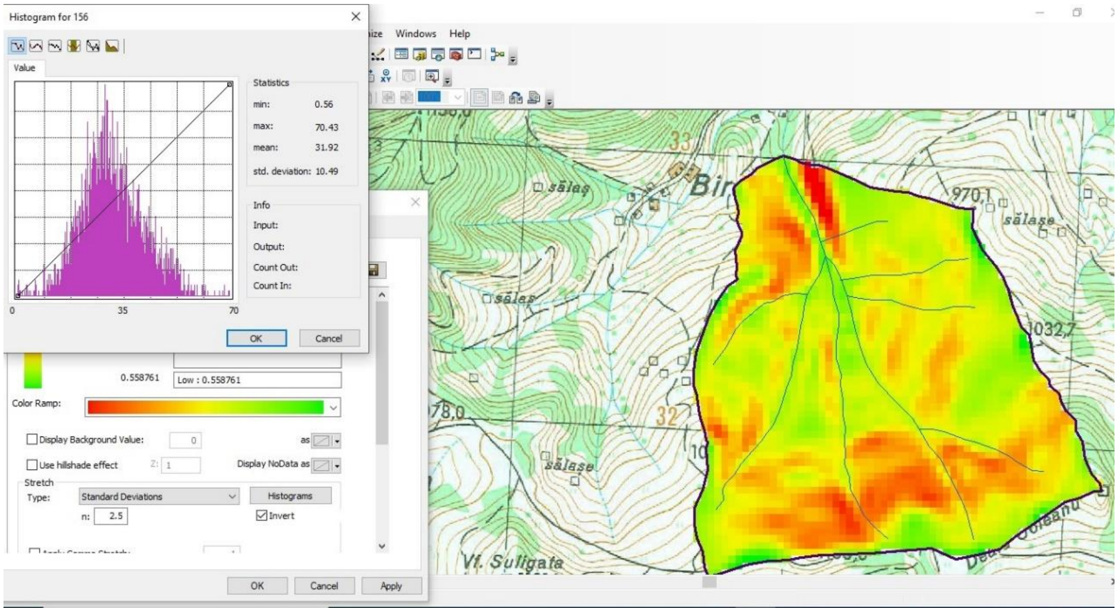

Figure 6. Roșia Poieni river basin

A degree of subunit elongation suggests an elongated shape, as observed in the Brata basin and a supraunit ratio a fan shape, open (Roșia Poieni), which in the case of small hydrographic basins favors the rapid concentration of waters in the emissary. Such small areas with large widths are also found in the Ocolișel, Valea Întunecată and Pârâul lui Toader basins, favoring the formation of the maximum discharge.

The values of the average slopes within the hydrographic basins have a significant influence on the run-off of surface waters, determining the speeds of displacement, of water flow on the slopes of the basin.

The slopes of the watersheds are important for the study of the probabilities of the occurrence of floods, for the analysis of the vulnerability to collapses and landslides, but also for a sustainable planning and management of how land is used in the vicinity of human settlements. The distinct forms of the geographical landscape are given by the qualitative functions of the slopes through the transformations they condition, the slopes representing the most important factor of influence on the maximum discharge (Irimuș et al., 2005). At high values of the slope (Toader's Creek – 39.8%) higher water drainage speeds can be recorded on the slopes resulting in a lower concentration time (40 min) (Figure 10).

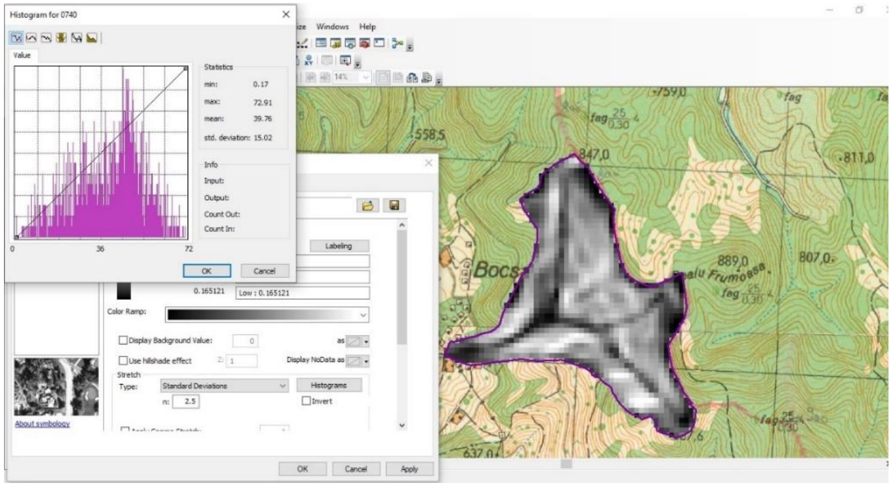

Figure 10. Pârâul lui Toader river basin

The values of water concentration times in the emissary increase in situations where the average slopes of the river basin slopes decrease, for example in the Silvașu_4 basin (34.4%), thus slowing down the rate of water runoff and increasing the concentration times to 82 min (Figure 11).

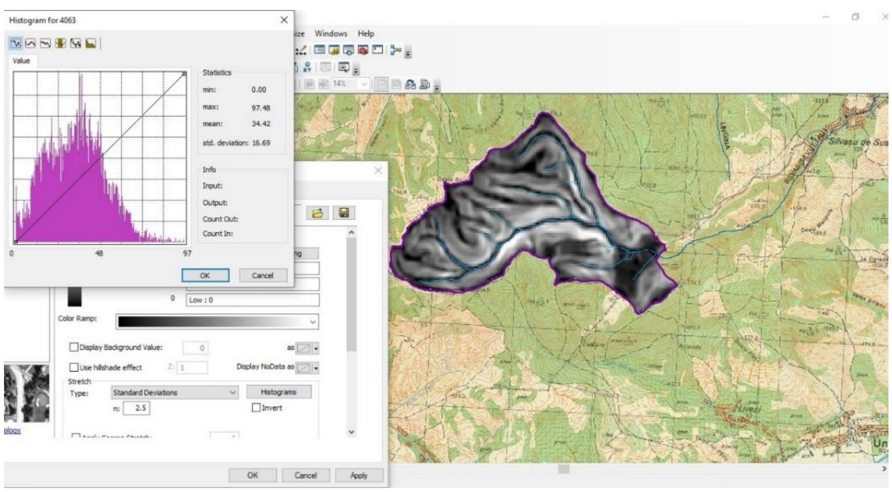

Figure 11. Silvașu_4 river basin

The correlations made between the morphometric parameters and the maximum leakage reveal intensifications of the maximum leakage with a probability of 1% in the hydrographic basins with areas between 10 and 50 sq km, which can be increased to values above 10000 l/s.kmp in small basins with areas below 10 sq km. The average altitude correlates with the maximum leakage layer with a probability of exceeding 1%, which has higher values in the Subcarpathian and mountain regions (70-120 mm), compared to 45-65 mm as recorded in the plateau regions (Voda, 2007).

4.2. Afforestation coefficient and crop associations

In the calculation of the maximum leakage, the vegetal associations are of particular importance in terms of typology and the degree of expansion on the analyzed basin areas. The most considerable influence on surface runoff is exerted by forest vegetation. It is necessary to determine the degree of afforestation, made on the basis of maps, satellite images, cadastral data and existing forestry studies. Specify the type of forest and calculate the afforestation coefficients for the sectors of basin taken into consideration, mentioning the areas covered by fruit tree orchards, vineyards, various crops, meadows and natural grasslands.

The increase in roughness, of the infiltration rates, favors the retention of water in the soil with the effect of mitigating the maximum leakage and compensating for the minimum leakage. The values of the drainage coefficient decrease to 0.48 with the increase of the basin areas to 5.49 sq km in the Cărbunarilor_5.49 basin compared to the Cărbunarilor_1.39 hydrographic basin with an area of only 1.39 sq km but with the same degree of afforestation of 100% (Figure 15).

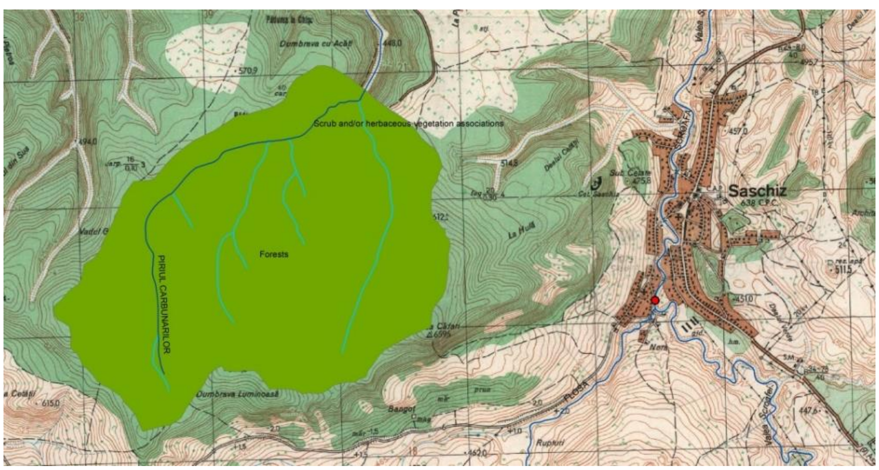

Figure 15. Cărbunarilor_5.49 river basin with 100% afforestation

The forest vegetation present in the analyzed watersheds protects the land against erosion and sliding processes. It can be noted the role of a more efficient protector of deciduous forests, hornbeam (*Carpinus betulus*) in the basin Cărbunarilor_5.49, beech (*Fagus silvatica*) in

Ocolișel_1.03, Valea Larga compared to that of resinous forests due to the role of protection against erosion played by the leaf litter cover.

The grassy vegetation with species of *Festuca*, *Descchampsia*, *Nardus* protects the lands except for the areas with high slopes (41.94% in the basin Ocolișel_1.03, 34.63% in the Valea Largă basin) and excessive grazing, where there is an intensification of erosion processes and a more accentuated drainage of water on slopes with drainage coefficients of 0.58 in Valea Largă.

The lack of forest vegetation favors the maximum drainage on the basin areas used in agriculture improperly, with ploughing along the slope line and not along the contours, even in conditions of low slopes of 8.7% (Vișa), soils with an average texture of 2 (Birt, Gypsies, Vișa), found in the hydrographic basins with average altitudes of 357 m - Vișa.

Legal or illegal deforestation has negative effects on maximum runoff from small river basins. The presence of pastures in the upper basin of Alămor determines the intensification of the surface runoff (Cs = 0,69; Q1%=74.37) in the conditions of excessive grazing and the presence of hard-textured soils (2.85) and urbanized areas favors the rapid transit of water quantities from precipitation, especially those within maximum 24 hours.

The highest values of the runoff coefficients, Cs=0.69, but also of the maximum flow with insurance of 1%, Q1%=74.37 were determined in the hydrographic basin at Alămorului, with a very low degree of afforestation of only 6%, stagnant luvisols and luvice faemoziomuri of heavy texture (2.85).

4.3. Influence of soils on maximum runoff.

Soils influence the processes of runoff by their typology (FAO, 2009), texture (light, medium, heavy), structure, erosional state, spatial position and expansion on the basin surface. By virtue of its properties, water infiltration capacities from precipitation, the soil can have a role as a regulator of surface water runoff, causing higher values of runoff coefficients in the case of heavy textures and lower values on soils with medium or light texture, under similar conditions of slope, respectively afforestation coefficient (Irimuș et al., 2015; Costea et al., 2022; Strapazan et al., 2021; Dornik et al., 2016). The processes of water infiltration are favored in loose and dry soils, which due to the sandy texture causes the capture and retention of water in the soil. A reduction in surface run-off of surface waters can thus be observed. A lower water retention capacity is presented by soils with heavy clay texture (2.85) such as stagnant luvisols and luvic faemozioms in the Alamor hydrographic basin, on which the maximum values of water runoff are recorded (Cs = 0.69; Q1%=74.37) of all the 51 basins analyzed.

The diminished storage potential of hard-textured soils favors a rapid transit of floods, unlike soils with a high infiltration capacity on which the maximum runoff is diminished. A number of seven small watersheds out of the 51 analyzed have a heavy texture (>2.5): Alămor (2.85), Lunca Satului (2.85), Borzeşti-2.61, Șomoșd (2.7), Hetiur (3), Cerghizel (3) and Mesendorf (3).

4.4. The importance of precipitation in the formation of runoff and floods occurence.

The maximum runoff varies in direct proportion to the altitude and inversely proportional to the size of the basin areas (Ditthakit et al., 2021; Psomiadis et al., 2020). The highest values are generally recorded on the slopes with western exposure. Representing the most important phase of the regime, the maximum runoff influences most strongly the human settlements, agricultural crops and industrial objectives, the calculation of maximum flows being essential in the design of civil and hydrotechnical constructions (Costache & Zaharia, 2017). A number of fourtyfive significant floods occurred in the last century with a frequency of about ten years, with very large floods in consecutive years: 1903-1904, 1912-1913, 1924-1925, 1932-1933, 1955-1956, 1974-1975, 1984-1985, 2004-2005. The seasonal variation of floods is illustrated by their higher frequency in the spring season (30%-45%). A smaller number of floods are recorded in autumn (6%-10%). The highest number of floods are reported in April and March, followed by June (Voda, 2007) (Figure 41).

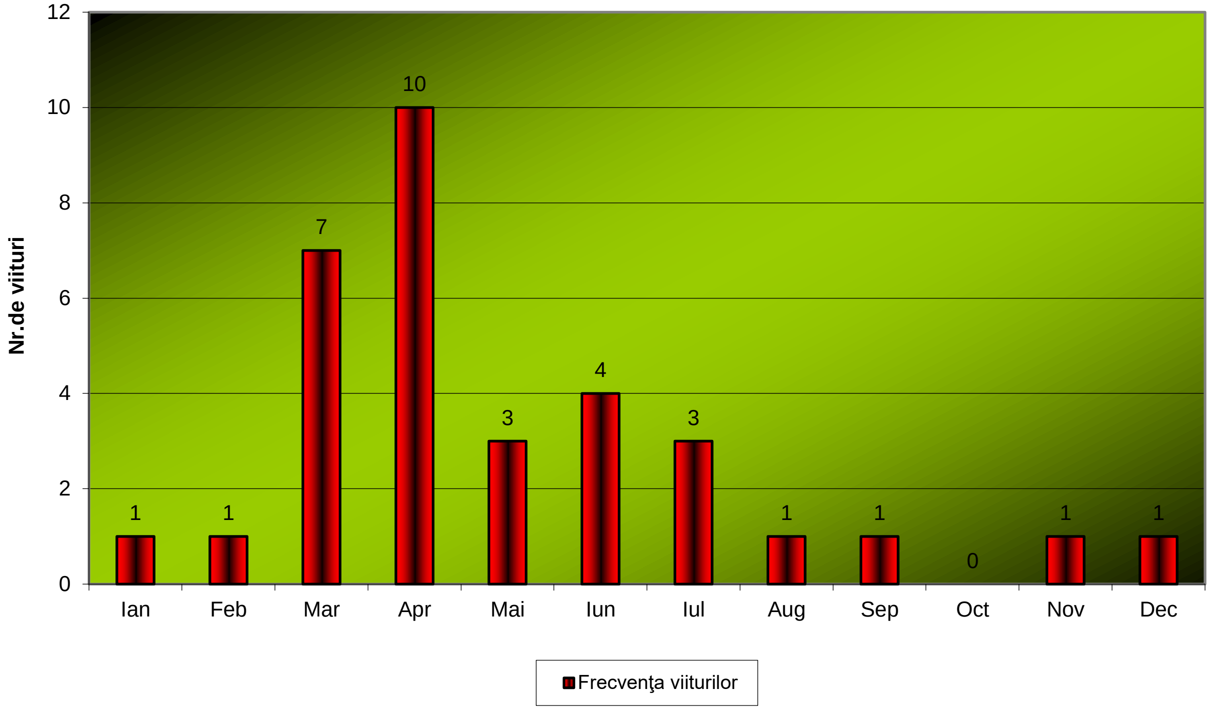

Figure 41. Monthly frequency of floods at the hydrometric station Sărăţeni (Voda, 2007)

Small watersheds in Romania have been affected by extreme hydrometeorological events in the last 30 years. After 1989, no important hydrotechnical works were carried out to mitigate the floods, while there were significant changes in the typology of the land cover. This research tries to quantify the most effective methodologies for calculating the maximum runoff discharge in the small watersheds without measurements in Romania, where floods tend to form faster. We used the rational methodology to calculate the maximum discharge taking into account the average intensity of precipitation and the values of the leakage coefficient (Figure 42).

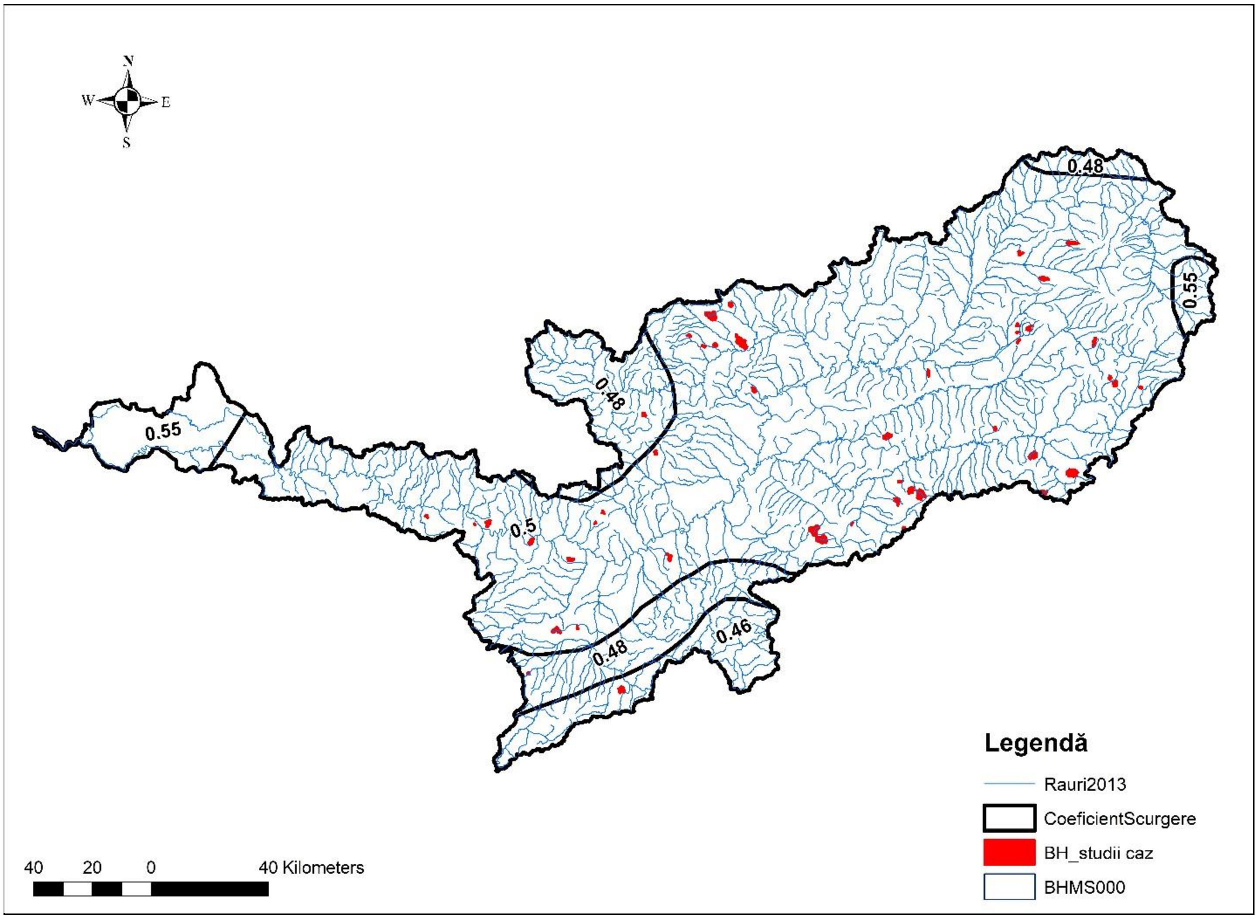

Figure 42. Spatial distribution of runoff coefficients (Diaconu and Miță, 1997)

The most important hydrological event represented by the flood on Feernic, the right tributary of Târnava Mare was analyzed in order to show how the uncertainty of the effects of climate change can be reduced and to be able to make better predictions for the precipitation-drainage relationship of the hydrographic basins.

Research illustrates that human activities have had a significant impact on natural water balance in small basins without measurements. Costache & Zacharias (2017), Kocsis et al. (2022), Ditthakit et al. (2021), Psomiadis et al. (2020) also demonstrate the role of environmental factors in the genesis of maximum discharges, the importance of satellite image accuracy and the importance of ArcGIS shapefiles for objective assessment of watersheds

The historical floods produced in the Mureş hydrographic basin are those recorded in the years 1970 (May), 1975 (July), 1981 (March), 1995-1996 (December1995 - January 1996), 1998

(June), 2005 (August), 2010 (July). The quantitatively rich precipitations determined the production of the floods with the generation of significant peak discharges the main course of mures, Târnava Mari, Târnavei Mici, Arieşului, as well as on their tributaries.

4.5. The role of anthropogenic factors and their influence on runoff formation

The anthropogenic factors that favor the formation of the peak runoff aggravating in some situations the maximum discharges refer to the anti-erosion works, the measures for the correction of torrents, the intensive deforestation activities associated with the non-observance of the forest rules for the grubbing-up or placement of the waste resulting from the felling of the trees (Figure 53), agricultural activities not complying with ploughing carried out perpendicular to the level curves on the high slope alignment, as well as inadequate activities of authorising and locating civil engineering near the banks of water bodies.

Figure 53. Wood waste in the Catariga catchment area

Uncontrolled deforestation, inefficient agriculture, in which terraces and ploughing are not carried out along the level curves, lack of anti-erosion works, non-existence of works for the arrangement of torrents, determine the increase of the runoff coefficient and maximum discharges in small hydrographic basins without measurements. The peak runoff is influenced by the hydrotechnical works represented by storage lakes, bank impoundments, riverbed regularizations, hydroameliorative works and water-consuming uses.

5. The results of the research carried out in the calculation of the maximum discharge from the small and unmonitored watersheds

In small basins, rain falling on a given area is distributed and concentrated in a different way than the same rain on the areas of a large river basin. After Costache et al. (2015), Şerban (2016), Tošić (2018), small basins are those river basins whose areas are not more than 10 sq km. Based on these considerations, the research was directed towards the identification of small river basins and the comparative analysis of case studies.

5.1. Spatial database analysis, delimitation of watersheds and preparatory calculation operations

The analyses were carried out following the spatial location and identification of the watersheds on topographic maps at the scale of 1:25000 using ArcGIS software. The field validation of the virtually determined data was carried out at all 51 analyzed river basins, the on-site checks being recommended especially in the case of the analysis of small river basins with areas below 5km^2. The inventories, interlockings and the analysis of the data fund necessary for correlations from the hydrometric stations were made on the basis of the hydrological background of data resulted from the standard hydrometric networks (ABA Mureș, 2021).

For the calculation of the maximum discharges in the analyzed small basins, it was of particular importance to know the rains and the coefficients of their transformation into runoff. The obtained results confirm the researches of Diaconu and Șerban (1994), which highlight the fact that the maximum hourly precipitation used in the Romanian practical hydrology has values between 100 mm (Calva), 115 mm (Moșna, Alămor, Filea, Lunca Satului, Sângerei, Velt, Roadeș, Pruniş, Cărbunarilor, Pârâul lui Toader), 125 mm (Catariga, Feernic, Silivașu, Șugău, Șomoșd), 130 mm (Roșia Poieni, Ocolișel) and 140 mm in Valea Lupului river basin.

It can be stated that the conditional factors of the peak discharge are the most dynamic and time-variable can be considered the basin facies, respectively the typology of the components of the analyzed basin areas. According to Diaconu and Miță (1997), the erosional processes that lead to the degradation of the slopes represent an important natural influence on the maximum runoff in small basins. Anthropogenic activities, materialized by uncontrolled felling of trees, afforestation or construction actions, exert pressures and modifications of the water drainage surfaces, by increasing or decreasing the concentration times and implicitly of the runoff coefficients.

5.2. Determination of curve number index (CN) and its role in maximum discharge analysis

The determination of the curve number is of particular importance because this indicator reflects the runoff potential of different types of land that can be encountered within a river basin. However, the question that arises at the level of the correct estimation of the maximum discharge is whether this indicator accurately reflects the runoff potential, without generating errors (Ditthakit et al., 2021; Voda et al., 2019; Psomiadis et al., 2020).

The American SCS-CN methodology is based on land use and soil hydrological groups to determine the curve number (CN) index, which has values between 0 and 100, values that can illustrate the runoff potential of water on different surfaces, the impermeable ones, which favor the surface water drainage, having the highest values, as in our case 84.4 in the Mirăslău basin.

Within the analyzes performed, the Miraslău hydrographic basins with CN=84.4, Drojdii (CN=83,2), Filea (CN=82,6), Frata (CN=82,3), Velt (CN=81,2), Țigani (CN=81,2), Alămor (CN=80,7), Lunca Satului (CN=80,4) and Ighişul Nou (CN=80,2) are noted. These small watersheds, have the highest values of the CN curve number and therefore a significant runoff potential, according to the American SCS-CN methodology.

The Valea Pişchinţi basins, with CN=55.1, Feernic_1.31 (CN=54.1), Cărbunarilor_1.39 (CN=64.2), Cărbunarilor_5.49 (CN=64.2), The Dark Valley (CN=65.4), Feernic_0.3 (CN=65.1), Bejan Valley (CN=65.7), Feernic_0.17 (CN=65.3), Brata (CN=65.4) have the lowest values of the CN curve index, being classified, based on the SCS-CN methodology, in the category of hydrographic basins with a low drainage potential.

5.3. Analysis of the calculations of the maximum discharge by means of the rational method

The rational method is the most direct way of quantifying the maximum discharge, which takes into account all the parameters that play an important role in the runoff formation. In calculating the maximum discharges, account must be taken of the nature of the surfaces, of the basin facies, by morphometric analysis of the watercourses, of their beds, of the slopes, of the degree of forest vegetation cover, of the land use method, of the soil typology, in order to establish objectively the state of the hydrographic surface for which the determination of the roughness coefficients of the riverbeds and slopes will be carried out, of the water concentration times in the riverbed, respectively on the slopes and on the entire basin as a whole, of the runoff coefficients, of the intensity of the calculation rain and finally to obtain the maximum discharge with 1% assurance (Voda et al., 2019; Psomiadis et al., 2020; Voda et al., 2018).

Unlike the American SCS-CN method, which uses only two parameters that influence the runoff from a hydrographic basin, the rational Romanian methodology includes, in addition to soils and land use, the slopes of the riverbeds, the slopes of the hills and the roughness coefficients of the riverbeds (Ma) and of the slopes (Mv), especially important in determining the water concentration times in the riverbed (Ta), respectively on the slopes (Tv).

$$T_v = \frac{(1000 * L_v)^{1/2}}{M_v * I_v^{1/4} * h_v^{1/2}} \qquad (12)$$

In the formula for calculating the time of concentration of water on slopes (12) the parameters Lv – width of the slopes (Lv==0.55*F/sum of tributaries), Mv – the coefficient of rogosity of the slopes, Iv – the slopes of the slopes and hv representing the average intensity of the maximum runoff on the slopes (13) are used.

$$h_v(\text{mm/min}) = 0.06B_{1\%}(m^3/\text{s } km^2) \quad (13)$$

The water concentration times in the riverbed and the concentration times of the waters on the slopes shall be determined using the parameter B1 %. A first step in the preliminary calculations for application by successive approximations in determining the maximum discharges to be recorded on small river basins is the geospatial location of the basins for the identification of the parameter B1% respectively of the exponent 1-n expressed in the hydrological synthesises (Diaconu and Miță, 1997)) and of the basin facies that are relatively similar to the types of facies reflected by the synthesises elaborated at national level.

The parameter B1 % is adjusted by an iterative procedure so that the maximum flow rate calculated on the basis of the formula:

$$Q_{max1\%} = B_{1\%} * F^{(1-n)} \quad (14)$$

must coincide with the maximum discharge rate determined with the formula

$$Q`_{max1\%} = 16.7 * I_{r1\%} * C_r * F, \quad (15)$$

within an acceptable margin of error e = $(Q`_{max1\%} - Q_{max1\%}) / Q`_{max1\%}$. If the value e<0.05-0.1 we have $Q_{max1\%} = Q`_{max1\%}$ and if e>0.05-0.1 iterative calculation of Qmax1% is carried out until when e<5-10%.

C_r is the watershed runoff coefficient, and $I_{r1\%}$ represents the generating intensity of precipitation, directly dependent on the parameter $B1_{\%}$ by the concentration time of the surface runoff. The concentration time of the water on the basin (Tc=98) correlates with the values of the runoff coefficients (Cs=0,51), of the intensity of the calculation rain (Ip=0,85) and of the maximum discharge rate Q1%=10,91mc/s.

The lower values of the concentration times (Tv=42) of the waters on the slopes of the river basin Cărbunarilor_5.49 are due to the cleared areas on the left verant in the closing section.

In the Valea Lupului basin, the reduced values of the basin concentration time are obtained by means of the calculation formula which includes the concentration times of the waters in the riverbed and the concentration times of the waters on the slopes:

$$t_c = 1,2t_a^{1.1} + t_v \text{ (min)} \qquad (16)$$

In using the rational method, it is considered that the precipitation that generated the maximum discharge has a probability intensity p% which determines a peak discharge of the same probability p%. Precipitation that generates the maximum runoff shall be considered to be evenly distributed over the surface of the river basin. The highest values of the intensity of the calculation rain were determined in the watersheds Pârâul lui Toader (Ip=2,035), Şomoșd (Ip=1,992) and Ocolișel_1.64 (Ip=1,929).

$$i_{p1\%} = \frac{S_{1\%}}{(t_c + 1)^{\,n}} \qquad (17)$$

Where Ip is the intensity of the rain calculation with insurance of 1%; S1% is a numerical parameter, tc is the concentration time in minutes and n a reduction coefficient

The high-value runoff coefficients that have been calculated using GIS instruments after determining the texture of the soil, the degree of afforestation and the slopes in the Somosod (Cs=0.66) and Borzesti (Cs=0.64) basins are correlated with the high values of the intensity of the calculation rains and the low water concentration times in the reception basin. The rational formula represents the central axis of this Romanian method of calculating the maximum runoff, in which the maximum discharge, expressed in mc/s, with a probability of exceeding-insurance p%, is determined according to the average intensity of rain (expressed in mm/min which generates the maximum flow and which has the duration equal to the concentration time of the surface water in the basin), runoff coefficient and area of the river basin analysed (15).

$$Q`_{max1\%} = 16.7 * I_{r1\%} * C_r * F, \qquad (15)$$

C_r, is the watershed drainage coefficient $I_{r1\%}$ is the intensity of precipitation and F is the basin area in km^2

5.4. Maximum flow correlations determined by alternative validation methods

Hourly H- hourly rain

The hourly rain method has a formula that can be used to determine the maximum discharges with the probability of exceeding – equalling 1 % in the case of basins with an area between 5 and 100 km^2. (Mustață, L.,1991)

$$\text{Qmax1\%} = \frac{0{,}28(H_{60})_1\%\alpha F}{(F+1)^n} \qquad (19)$$

The lack of significant correlations between the values of the maximum discharges determined by the Horar method, the rational method and the method of the synthesis relations in the case of the Roșia Poieni hydrographic basin is explained by the reduced basin areas (F = 1.56 sq km).

Synthesis relationships

Synthesis relationships are a method of indirect analysis, when hydrometric data are insufficient, missing or unreliable, the values of the theoretical maximum discharges are determined by indirect methods materialized by synthesis relationships in graphic form or formulae. The best correlations between the maximum discharge calculated using the rational method and the other two methodologies generally used for verification were determined in the watershed Moșna_7.67.

5.5. Comparative analysis on the parameters of the maximum discharge TlagSCS, TlagR, CN_R , CN_{SCS}. SCS-CN methodology versus rational method

Comparative analysis of the TlagSCS lag times calculated by the SCS-CN and TlagR method obtained by the rational method was necessary for a better understanding of the differences between the results of both methods, SCS-CN and the rational method. We compared the same type of parameters: TlagSCS and TlagR lag times (Voda et al., 2019). The most appropriate equation of the lag time in the SCS-CN theory as a function of the power of the lag time in the Romanian national standard method is (Voda et al., 2019):

$$T_{L\ SCS} = 0.8207\ T_{L\ R}^{0.9398} \qquad (20)$$

A good correlation can be noted at a value of the coefficient r = 0.7626 while the ranges of variation of the TL SCS at certain values of the TL R are considerably wider. The causes of these variations can be considered as representing the effects of including parameters such as roughness, runoff coefficient and flow rate in the standard equation of the rational method (Voda et al., 2019).

The results of the comparative analyses carried out show us a shorter lag time obtained by the SCS-CN methodology compared to the rational method. Differences increase considerably in higher areas with higher altitudes, suggesting distinct processes of modeling precipitation-runoff relationships (Voda et al., 2019):

$$T_{LR} = 29.926 + 0.062\ F \qquad (21)$$

$$T_{LSCS} = 3.1049\ F^{0.4208} \qquad (22)$$

Where the delay times are expressed in minutes and the basin areas (F) are expressed in hectares. The differences in the delay time values range from 0.8 minutes (36.1 and 36.9 minutes respectively in the Feernic_1.73 basin) to 67.5 minutes (113.2 and 45.7 minutes respectively in the Filea basin).

Due to the fact that only the SCS methodology involves the use of CN parameter, we performed regressive calculation operations (reverse CN_R) to obtain the delay times using the rational method and the hydro-morphological parameters (Voda et al., 2019).

6. Discussions on the limits and challenges in research on maximum discharge.

The researches carried out on the maximum runoff from the small hydrographic basins without hydrological measurements managed to highlight the efficiency of the rational method within the standard methodologies used in the calculation of the maximum dischargess from the unmonitored basins of Romania. The uncertainties related to the correctly determined values of the parameters influencing the flow of rivers have been presented and explained, with continuous comparative analyses and verifications of the results obtained by different methods being carried out on an ongoing basis.

It is recommended to expand the hydrological database, adjust and update the data on the typology of soils in order to facilitate the adaptation of the SCS-CN methodology to the geographical characteristics of our country. The results of the research carried out on the 51 small hydrographic basins without measurements show us that, compared to the rational method used mainly in Romania, the SCS-CN methodology leads to shorter delay times and to a faster forecast of the evolution of the maximum runoff, as it results from the equation $T_{L\,SCS} = 0.8207\ T_{L\,R}^{0.9398}$ (6) (Voda et al., 2019).

A good knowledge in the field of the analyzed hydrographic network, as well as the experience gained over the years in the processing and interpretation of hydrological data, has led to the avoidance of uncertainties regarding the results obtained in the calculation of the maximum discharge from small basins without measurements.

Conclusions

The results of the researches regarding the maximum runoff in the small basins without measurements highlight the significant adaptability of the rational method to the geographical characteristics of the Romanian hydrographic basins and especially to those in the Mures River basin. The determination of the maximum discharges is more accurate, and the duration of the concentration time remarkably follows the variation of the parameters that influence the runoff.

The evolution of the surface of small watersheds without measurements, of the runoff coefficients, the effects of roughness coefficients on the precipitation-runoff system are all quantified in the rational method used to calculate the maximum discharges.

The rational method is much more flexible and the duration between the core of the rain and the moment of reaching the maximum faithfully follows the variation of the runoff parameters.

The rational method can be improved by updating the currently existing GIS database. More recent shapefiles of soils, land use, coverage, slopes are required. The hydrographic maps of Romania must be renewed in order to know the updated state of the watercourses, of the riverbeds, the nature of the surfaces and the degree of vegetation coverage. An important aspect for the future is the improvement of the adjustment process of the American soil groups used in the SCS-CN methodology to the Romanian typology.

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