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DOCTORAL SCHOOL OF CHEMISTRY, LIFE AND EARTH SCIENCES

CHARACTERISTICS OF LIQUID AND SOLID FLOW IN THE REPRESENTATIVE DRAINAGE BASIN OF SUHA (BUCOVINEANĂ)

-DOCTORAL THESIS ABSTRACTS -

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Contents:

PART I
GENERAL ASPECTS

PART II
NATURAL REGIME OF RIVER FLOW

PART III
HYDRAULIC MODELLING

List of figures

List of tables

1. Introduction

At the moment, the knowledge of water resources, as one of the country's riches, is a primordial preoccupation. In this sense a special attention is given to drainage basins as areas of formation and organization of surface flow. The role and importance of rivers is generally well-known, yet in particular, besides the undeniable richness they represent, they have also raised problems for population both through the available quantity of water and the time variation of discharge rates which has as effects catastrophic floods and severe droughts. The promptitude in identifying and signaling the possible extreme hydrologic events stands at the base of avoiding a whole spectrum of negative effects such as erosion and landslides, the destruction or damaging of infrastructure, of human settlements or of economic and social objectives, or even the loss of human lives.

Through the structure and contents of this paper, we desire to evidence the distinct geographic personality of a relatively forested, but well-populated drainage basin, by elaborating a thorough and unitary analysis of the evolution of hydrologic phenomena. At the same time we had in view computing flooding scenarios conditioned by a series of important factors such as: geology, geomorphology, soil and climate, land use and human influence.

The analysis of the general landscape conditions of Suha drainage basin is essential for understanding the multitude of factors that interfere in the natural regime of river flow. In this sense we mention the fact that Suha basin is situated in the Eastern Carpathians and mostly corresponds to the flysch area of Stânişoara Mountains, only its western extremity being situated in the crystalline area of Rarău Massif. It occupies the southern part of Obcina Feredeului, the southeastern slope of Rarău Massif, the eastern one of Ostra and Suha Mountains and the north-western part of Obcina Voronețului (Sârcu, 1971; Posea, 1972; Roșu, 1973; Ichim, 1979; Velcea et. al., 1982; Barbu 1987; Pop, 2000; Rusu, 2002) (Fig.1).

In studying the variability of surface flow has been identified significant oscillations determined by the un-uniformity of climatic parameters, the most important being air temperature and rainfall regimes. The values recorded for the 1979-1998 period show the fact that mean annual air temperature in the basin is of 5.9^0C. As regards the thermal regime of river water, it is directly influenced by meteorological factors that determine thermal exchanges between air and water, as well as by the water flow speed, discharge rates and alimentation sources.

Rainfall regime is determined by the influence of atmospheric pressure centers, and its oscillations have been analyzed from the recordings made at Gemenea 1, Gemenea 2, Vadu Negrilesei and Stulpicani hydrometric stations. The recordings show a high variability, with significant differences from a month to another at the basin scale, the highest quantity being recorded during summer and the lowest during winter. The interpolation of rainfalls recorded in the basin and the neighboring areas indicate that the lowest quantities are found in the depression area of the basin, along the main valleys (around 627-650 mm). As altitudes increase so do rainfall quantities, reaching over 850 mm in the highest points of the basin. As a conclusion, the mean annual rainfall in the basin is of 714.86 mm. Very important from the hydrologic point of view are the maximum rainfall quantities in 24 hours, because these do not infiltrate entirely and accelerate the flow process, generating significant floods (Brook et al., 1953; Apăvăloaie et al., 1975; Alila, 1999).

By interpolating the values registered at the stations in the basin and the neighboring rainfall gauges resulted a distribution of maximum rainfall quantities in 24 hours in eleven classes. The lowest quantities are again recorded in the lower area of the basin, where they do not exceed 97 mm/24 h, while the highest values have been recorded in the areas with higher altitudes (up to over 135 m).

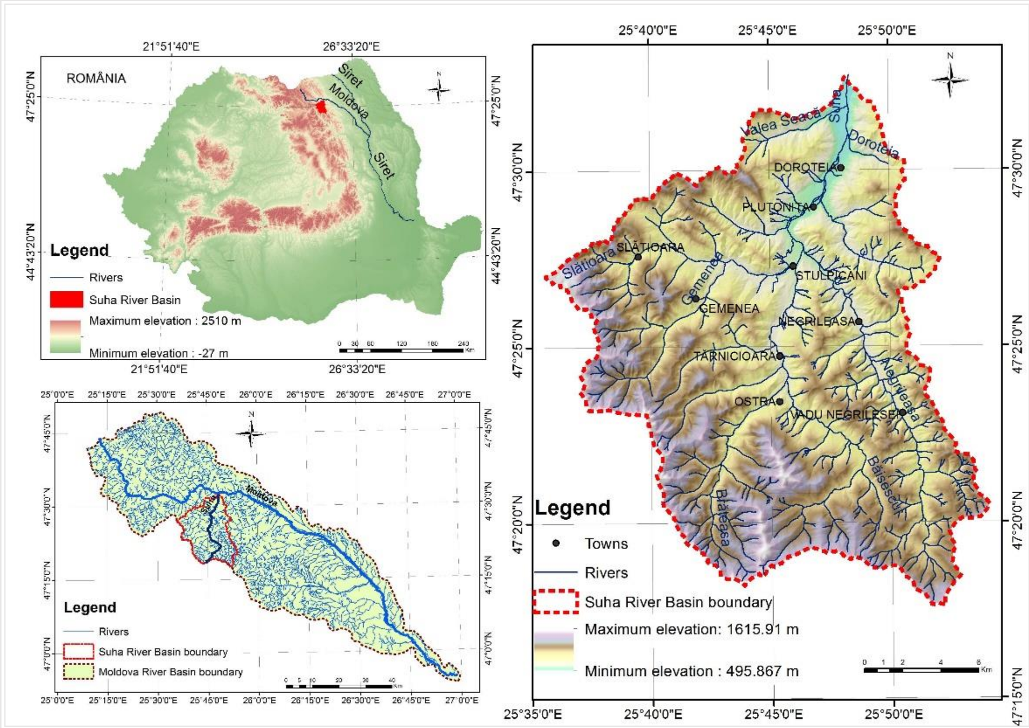


Fig. 1 Geographic location of Suha basin

2. Data and methods used in the analysis

The scientific support of the present paper is represented by the quantitative and qualitative variety of data recorded and used from numerous older or more recent references, mentioned both in the subchapter elated to the history of research as well as in other chapters. The geographic location of Suha drainage basin has been established based on the papers of Ichim (1979) and Rusu (2002) and topographic maps (1980, 1984). The data related to climate aspects have been taken from Rarău and Câmpulung Moldovenesc meteorological stations and from the hydrometric stations inside the analyzed basin, from neighboring hydrometric stations and from special reports at basin or national level (***1960; Apostol et al. 1991, 2010; IPCC, 2014, http://www.wmo.int).

The geological features have been extracted and analyzed based on the following papers: *Geological Map of Romania*, *scale 1:200 000*, elaborated by the Romanian Geological Institute (1960); *Geological Map of Romania, scale 1:200000, Sheet Rădăuți: L-35-II* (1958) (interpreted after Băncilă,1958). Geomorphological characteristics have been taken from papers of Ichim (1979) and Rusu (2002), while the morphometric ones have been determined using the digital elevation model scale 1:5000 and 1:25000 (1968; 1983). Soils have been identified from *Soil map of Romania, scale 1:200000, Sheet Rădăuți* and adapted according to Florea et al. (2012). Land use has been extracted from the Corine Land Cover database (1990, 2000, 2006), adapted from http://www.ifen.fr/donIndic/Donnees/corine/clcmeth.htm and http://www.indd.tim.ro/CLCweb/index.htm and completed with local (1987, 1990, 2004) and national (ANCPI, 2012) statistical data. Hydrological data have been obtained during years through a sustained activity of measurements and observations in hydrometric stations of the Siret Water Basin Administration Bacău, the National Institute of Hydrology and Water Management and Suha hydrological station, and they include time series of liquid and solid discharge, as well as data and observations of climatic parameters for a period of 30-40 years. The selection of hydrological data sets has been conducted according to several criteria elaborated by Bîrsan et. al. (2005), taking into analysis complete and homogeneous data sets.

The mean values of flow rates have been extended through correlations between x values to whom another y corresponds. The whole database has been analyzed through statistical and graphic methods (Pearson III, Krițki-Menkel). As informatics applications have been used Microsoft Excel and ArcGIS 10.1 together with the ArcScreen extension. Water quality data have been taken from Siret Water Basin Administration, Bacău and interpreted according to existing standards. Hydraulic modeling has been done in ArcGis 10.1 and Hec-Ras software. The main objective has been of identifying floodable areas and buildings affected by floods with an occurrence probability of 100 years.

Modern georeferencing and vectorization methods have been applied for the 95 sheets scaled 1:5000, respectively 1:25000 for generating the digital elevation model. The hydraulic modeling method has been applied for seven sectors on the rivers from the Suha basin, established through classical and modern methods (1985). In elaborating the hydrologic prognoses have been used both classic and modern methods. The classic ones stand in computing the flow rates corresponding to Ursoaia closing station, while the modern ones use the River Forecast System (RFS) application and information coming from automatic stations.

3. Results

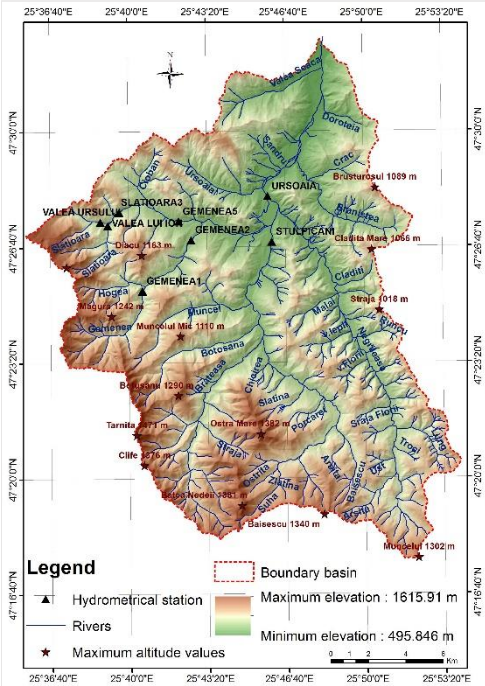
3.1 Variability of liquid and solid flow

The variability of the natural regime of surface flow in Suha basin shows the fact that the alimentation of the drainage network is done mainly from rainfall and secondarily from groundwater. Its monitoring is made at existing hydrometric stations and through correlations for the area which are not continuously monitored (Fig. 2)

The analysis of the **mean annual discharge** on the river courses of the basin shows that it has a mean value of 0.426 m^3/s for the 1950-1998 period and 0.507 m^3/s for 1999-2013. These values can be separated into several periods of discharge regime:

- ✓ the 1950-1984 period is characterized by values above the mean, and the mean maximum value recorded has been of 2.93 m^3/s in 1981;
- ✓ in the 1985-1987 period the values have been lower than the annual mean, with the lowest value in 1987 of 0.033 m^3/s;
- ✓ in 1990 have been recorded very low values;

the 1991-1998 period is characterized by high values, the maximum being recorded in 1996, of 1.11 m^3/s.



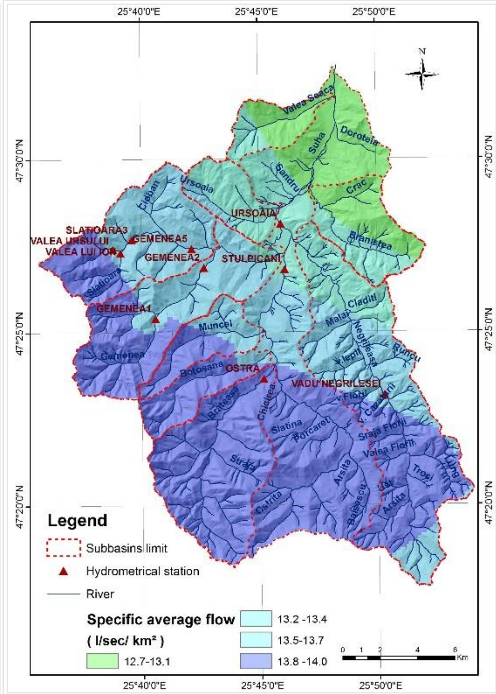


Fig. 2 Geographic position of the drainage network and present hydrometric stations in basin
Fig. 3 Distribution of specific mean annual flow rates in Suha basin

For the second period, values of flow rates above the mean have been recorded in 1999, 2001-2003, 2005-2008 and 2010, and values smaller than the mean in 2000, 2004, 2009, 2012, 2013. In the analysis of liquid flow rates in a drainage basin the most important factor is considered to be specific discharge. Computing it based on data specified before it resulted that in Suha basin specific discharge have values between 12.7 and 14.0 $l/s/km^2$ (Fig. 3).

The analysis of **maximum liquid flow** has evidenced the fact that during 1973-1998 the mean annual maximum discharge has been of 20 m^3/s, while for the 1999-2013 period the values was of 16 m^3/s. Still the largest recorded flow rates have been in 1973-2013 during flash floods: in **1981** on Suha have been recorded 175 m^3/s and on Negrileasa 84 m^3/s (Fig. 4 (left); Fig. 4(right)). In ***2006*** on Gemenea river at Gemenea 2 hydrometric station have been recorded 68.9 m^3/s (Fig. 5, left), and at Gemenea 5 station 38.8 m^3/s (Fig. 5, right). In **2008** the maximum discharge recorded at Gemenea 2 station has been of 68.8 m^3/s ((Fig. 6 left) and at Gemenea 5 station of 95.3 m^3/s (Fig. 6 right). From the existing data it results that in Suha basin the most frequent floods are those with a relatively short occurrence time, between 24-48 hours, whose discharge rates are not catastrophic. The rarest are those with a total time of 113-156 hours, recorded in the entire basin, and who reach discharge rates with an insurance of 2%.

The analysis of **minimum discharge** revealed the fact that the years with the lowest rainfall quantities have been 1969, 1974, 1978, 1983, 1987 and 2001. The manifestation has been isolated, on limited areas: on Gemenea river at Gemenea 2 hydrometric station the historical minimum discharge of 0,000 m^3/s was recorded on 02.03.1969 and also on 01.10.2001. On the same river at Gemenea 1 station the minimum historical discharge was recorded on 08.12.1969; on Slătioara river at Gemenea 5 the minimum historical discharge of 0.000 m^3/s has been recorded on 23-25.01.1974. At Slătioara 3 station the minimum historical discharge has been of 0.008 m^3/s on 13.01.1978, at Valea Ursului hydrometric station the minimum discharge of 0.001 m^3/s on 15.12.1983. At Valea lui Ion hydrometric station the minimum historical discharge recorded has been of 0.006 m^3/s on 08-25.09.1987. On Suha minimum discharge rates have been recorded in 2001, of 0.009- 0.035 m^3/s at Stulpicani hydrometric station (17-24.01.2001). In this sense, the determination of minimum discharge with different probabilities of occurrence has as purpose the identification of water resources for periods with reduced discharge rates.

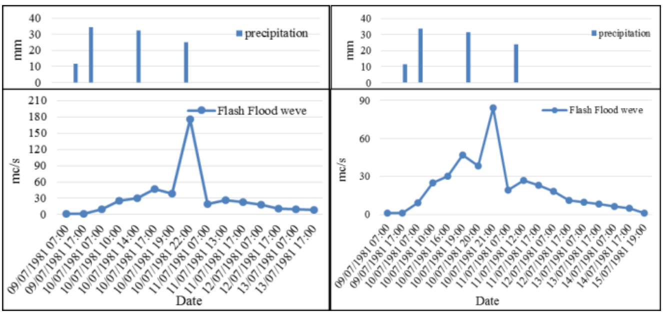


Fig. 4 Largest flash flood recorded on Suha - 1981(left); Flsh flood on Negrileasa river in 1981(right)

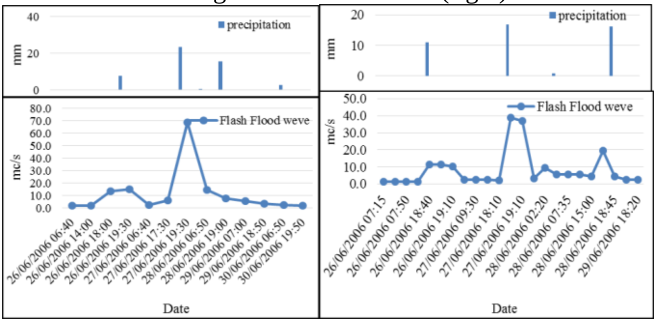


Fig. 5 The flood from 26.06-30.06.2006, Gemenea 2 (left) and Gemenea 5 (right) hydrometric stations

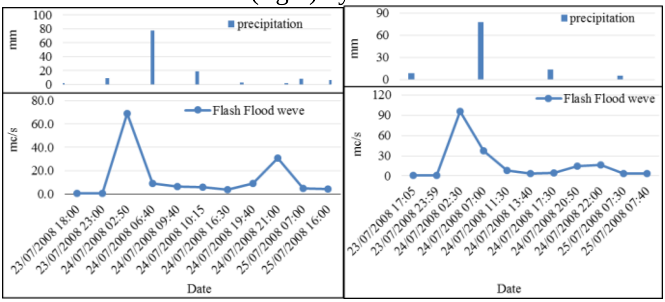


Fig. 6 Flash flood from 23.07-25.07.2008, Gemenea 2 (left) and Gemenea 5 (right) hydrometric stations

Oscillations of suspended alluvia discharge rates and their sources

The largest quantities of alluvia come from slope mass movement processes and from erosion, being registered in the periods with large flows. In the periods of low flows their value is close to zero. The largest quantities of maximum solid discharge have been recorded in 2008 at Gemenea 1 hydrometric station (418 kg/s), in 2006 at Valea Ursului (5.60 kg/s), in 2008 at Slătioara 3 (219 kg/s) and in 2006 at Gemenea 5 station (880 kg/s).

3.2 Generating flooding areas

The probabilistic hydrologic computations that are conducted for a drainage basin have as purpose the identification of areas vulnerable to floods. This procedure is a complex one, which requires many resources and implies several stages, the quality of the results being directly influenced by the materials and methods used. The generating of floodable areas has implied several stages: creating the digital elevation model (Fig. 7); correcting water courses (Fig. 8); establishing the areas of interest on which modeling will be applied (Fig. 9); correct hydrological courses (Fig. 10); realizing a correct model from the hydrological point of view by correcting water courses (Fig 11); creating the GeoRas strata needed by the modeling software: River, Bank lines and Flow path strata, followed by the transversal profiles executed in Ras Geometry (Fig. 12-15); computing discharge rates with different probabilities of occurrence; running the discharge rates with 1% probability of occurrence; intersecting the resulting band with the shape of vectorized buildings and identifying the number of those affected by the flood (Fig. 16).

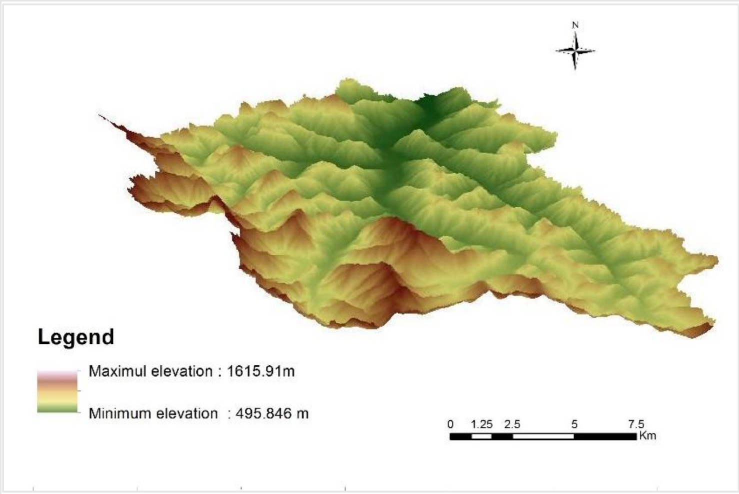
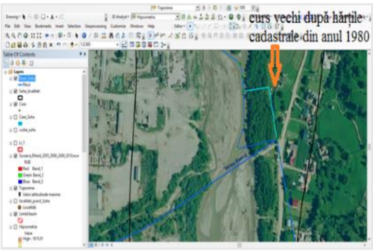


Fig. 7 Digital elevation model of Suha basin - ArcScene (2D) visualization



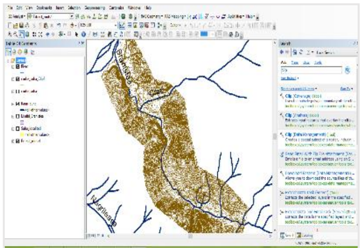


Fig. 8 Correcting water courses Fig. 9 Delineating areas of interest

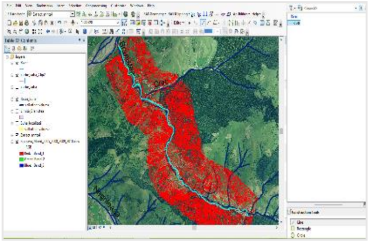


Fig. 10 The results of river courses correction

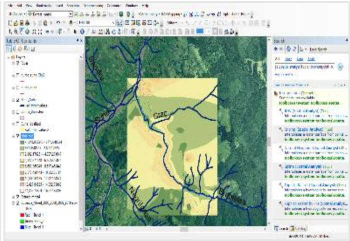


Fig. 11 Hydrologic ally correct DEM

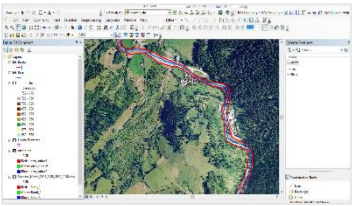


Fig. 12 Delineating river banks and course

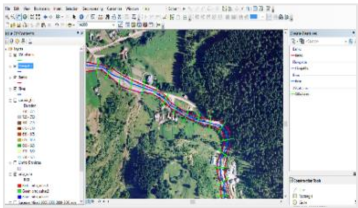


Fig. 13 Automatic creation of transversal profiles

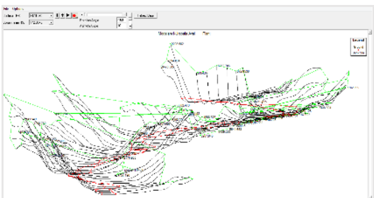


Fig. 14 Verifying transversal profiles

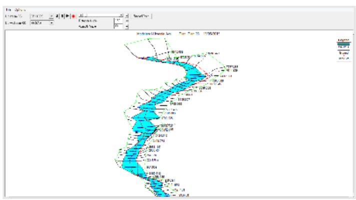


Fig. 15 Visualizing the results of discharge runnin

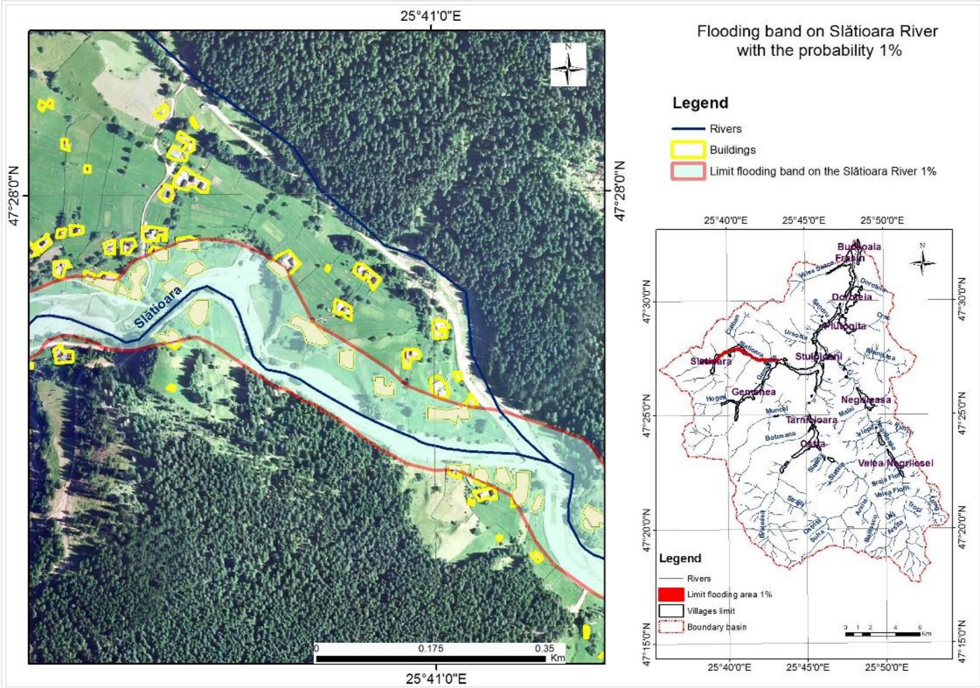


Fig. 16 Example running debt with probability 1 % on Slatioara rive

4. Conclusions

The paper "Characteristics of liquid and solid flow in the representative drainage basin of Suha" has been approached in the context of the hydrographic network concept defined by Ujvari (1957, 1959, 1972) and continued by Mustață (1970), Morariu (1982), Miță (1996), Romanescu (2003). This implied that the way of approaching the analysis is in a unitary context of the general characteristic in which the basin formed.

Suha drainage basin is a component part of the Eastern Carpathians and is overimposed on the flysch area, except its western extremity which is characterized by the crystalline formations of Rarău Massif. It was largely individualized during Mesozoic and Neozoic together with the entire mountainous area (Ungureanu, 2003). It presents a landform disposal into thrust nappes from west to east, has a surface of 365 km^2 and altitudes between 495.8 and 1615.9 m. The drainage network present a symmetrical disposal in relation to the main collector, while the presence of depression basins developed between the main tributaries together with the altitudes that decrease from west to east give the basin an aspect of amphitheater. The main climatic features are characterized by the presence of mean annual temperatures of 6.4^0C at Câmpulung Moldovenesc meteorological station, 2.3^0C at Rarău, 7.4^0C at Valea lui Ion and Gemenea 1 hydrometric stations, 6.8^0C at Gemenea 2 and 6.6^0C at Slătioara 3 and Vadu Negrilesei stations. Water temperature is directly influenced by meteorological factors that determine the thermal exchange between air and water, by water flow speed and by the discharge rate and alimentation sources, presenting positive values during March-November. Rainfalls present different values from the depression and valley areas to the mountainous peaks. The mean annual values are between 627-671 mm along the main valleys and in the depressions and increase in altitude up to 757-868 mm.

The surface flow regime from Suha basin is influenced by several factors characterizing this area. Besides its surface, in the flow process interfere: the length of the drainage basin whose value is of 28.02 km, the maximum width of 20.3 km, the basin development coefficient of 0.45, the asymmetry coefficient of 0.271, the mean altitude of the drainage basin of 879 m, landscape differentiation on altitudes with the following distribution: 8.21% of the basin surface in the higher altitudes, 48.22% with mean altitudes and 43.57% altitudes between 495-1000 m; the shape coefficient C=3.14. The calculation of basin slope declivities showed the following distribution: along rivers terrains have declivities lower than 5‰, the floodplain areas have declivities of 5-10 (5‰), interstream areas have slopes of 10-20 (5‰). The highest declivities, of over 25 (5‰) correspond to the western part of Suha basin.

The hydrologic regime of rivers in Suha basin supports the influences of groundwater input, of air temperatures, landforms, vegetation, soils and land use (Diaconu, 1956). The variations of mean annual values of discharge rates separate several periods of liquid flow. Thus, during 1950-1984 the discharge rates in Suha basin have had values above the mean; during 1985-1987 the values were situated below the basin mean. The year 1990 has been an extremely droughty one, while from 1991 up to 1998 the discharge values have been above the mean. The highest values of flow rates recorded at the hydrometric stations in Suha basin up to present are the following: in 1981 at Stulpicani station (2.93 m^3/s), in 1996 at Gemenea 2, (1.11 m^3/s), in 1999 at Valea lui Ion (1.40 m^3/s), in 1981 at Ostra (1.17 m^3/s), in 1991 at Gemenea 5 (0.793 m^3/s), in 1981 at Vadu Negrilesei (0.785 m^3/s), in 1991 at Gemenea 1 (0.404 m^3/s) and in the same year at Valea Ursului (0.166 m^3/s) station. In the seasonal distribution the highest values of surface flow are recorded during spring and summer, and the lowest ones during autumn and winter.

The values of maximum discharge rates follow the trend of the mean ones, being identified periods with high and low maximum flow rates. The years with the most significant maximum discharge rates have corresponded to those with heavy rains: 1975, 1979, 1981, 1982, 1984, 2005, 2006, 2007, 2008 and 2010. The historical floods registered in Suha basin have been in 1981 on Suha and Negrileasa rivers as a consequence of significant rainfall fallen especially in the eastern half of the basin, when the flow rates have been of 175 m^3/s at Stulpicani and 84 m^3/s at Vadu Negrilesei hydrometric stations; in 2006 on Gemenea river at Gemenea 2 station were recorded 68.9 m^3/s and in 2008 95.3 m^3/s on Slătioara at Gemenea 5 station as a consequence of front rainfalls on the western part of the basin.

From the analysis of the way floods manifest on the main river course it can be concluded that almost half of them have a total duration of 34-48 hours, while on the secondary courses 60% of the floods have duration of 21-33 hours. As a conclusion, most numerous floods form in a relatively short time and can provoke significant inundations. The periods with minimum flow rates have also a special importance for the population, the damages being at least as big as those of floods or even more severe. In Suha basin have been identified as droughty the years 1969, 1974, 1978, 1983, 1987 and 2001, when the rivers have had very low discharge rates and on some sectors have even dried. In the areas with thick alluvial deposits the phenomenon is not really a dry-out, but an infiltration of water in the floodplain bed deposits. From the analysis of the discharge rates oscillations in the basin it can be seen that in the last years an intensification of extreme phenomena was recorded.

The more and more intense populating of the Suha drainage basin has generated important modifications in the landscape, interfering in the normal process of surface flow through deforestations, exploitation of alluvial materials and reductions in the floodplain caliber, all these determining flood occurrence. To prevent such unpleasant and damaging events, the activity of hydrologists is to forecast possible events that may take place in the case of some given discharge rates. The analysis of the discharge rates recorded in Suha basin has pointed out that up to present they have not exceeded values with occurrence probabilities of 2% on Suha and 5% on its tributaries, and the damages inflicted have only been material, without putting in danger the population. The calculation and running of discharge rates with lower probabilities (respectively 1%) in specialized software and the superposition of the flooding bands resulted with the shape containing buildings in the basin had as result the floodability of built-up surfaces. These are distributed as such: on Gemenea river 81 buildings, on Suha 231, on Slătioara 90, 97 on Negrileasa, 60 on Valea Seacă, 119 on Brăteasa and 42 on Braniștea.

5.Keywords: Suha, catchment, basin control factors representative you spill, the maximum rainfall in 24 hours, the potential for transmission of hydrographic network, rivers in the Horton-Strahler system, liquid and solid flow, medium and maximum minimum, flash floods frecvency, gauging torrential groundwater basins, water quality, sources of pollution of surface water and groundwater, hydraulic modeling, digital terrain model, flooded study tapes, populațieie flood protection.

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