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DETECTION OF HYDROLOGICAL CHARACTERISTICS USING STATISTICAL ANALYSIS IN THE UPPER BASIN OF DESNĂȚUI RIVER, ROMANIA (1964 – 2011)

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Detection of hydrological characteristics using statistical analysis in the upper basin of Desnățui River, Romania (1964 – 2011)

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Identificarea caracteristicilor hidrologice utilizând analiza statistică în bazinul superior al râului Desnățui, România (1964 – 2011). Studiul de față își propune să realizeze o serie de analize pe bază de reprezentări grafice și matematizări ale celor mai importante șiruri de valori privind scurgerea medie lunară și anuală, hidrografele viiturilor, puse la dispoziție pentru stația hidrometrică Dragoia, situată în sudul bazinului superior al râului Desnățui, cel mai important bazin afluent al Dunări, în spațiul dintre râul Cerna și Jiu. Datele numerice au fost evaluate prin metodele hidrologiei frecvențiale, scenariul temporal rezultat în urma prelucrărilor statistice evidențiind tendințele interanuale ale evoluției debitelor, acestea fiind corelate și cu trăsăturile geografice ale bazinului, în special regimul climatic și particularitățile scurgerii în albie. Rezultatele cercetării s-au dovedit utile pentru a trasa managementul general al resurelor de apă ale bazinului, acestea constituind o cale științifică de a demonstra vulnerabilitatea resurselor intermitente de apă ale bazinului, ca parte componentă a Piemontului Getic, precum și lipsa de siguranță în a prognoza caracteristicile și amploarea unei viituri sau durata scurgerii de etiaj.

Cuvinte cheie: analiza statistică, râul Desnățui, corelații ale debitelor, tendințe hidrologice, România.

Detection of hydrological characteristics using statistical analysis in the upper basin of Desnățui River, Romania (1964 – 2011). This study focuses on the graphical and mathematical representations of some important hydrological datasets (annual and monthly mean flow, flood hydrographs) available for Dragoia hydrometric station, situated in the south of the upper sector of Desnățui river basin, the biggest first order tributary of Danube river between Jiu river and Cerna river. The data entries were evaluated after the frequential hydrology principles, the temporal scenario revealed by the calcula being correlated to the geographical features of the river basin, especially the climatic regime and the particularities of flow. The results of this research proved useful for the watershed management, constituting a scientific way to demonstrate the scarce of the surface water resources in this area of Getic Plateau, along with the uncertainty which rises when we try to predict the flood effects during peak rainfalls or the etiage flow intervals.

Key words: statistical analysis, Desnățui river, flow correlations, hydrological tendences, Romania.

1. INTRODUCTION

At the most general level, hydrological studies are based on complex statistical analyses which commence with the identification of a river's hydrological characteristics and progressively develop correlations between various parameters specific to its course and measured at hydrological stations.

Beginning in the 1970's, and more importantly in the last few decades, specialist's attention was drawn towards the hydro-climatic problems that generated significant disparities in the variability of certain hydrographical basins flow [1]. In this context, it is worth remembering authors such as Groisman et al., 2001 [2]; Pasquini and Depetris, 2007 [3], Cayan et al., 2001 [4]; Mote, 2003 [5]; Regonda et al., 2005 [6]; Stewart et al., 2005 [7].

At a regional level, Desnatui's river basin is included in numerous scientific works on hydrology: (Savin, 2008 [8]; Anuța, C., 2005 [9]; Boengiu, S., 2002 [10]; Drobot, R., 1997 [11]; Musy, A., 1998 [12]; Petrehuș, V., Popescu, S., A., 2005 [13]; Pișota, I., Zaharia, L., Diaconu, D., 2010 [14]) și geomorfologie (Coteț, P., 1957 [15]; Stroe, R., 2003 [16]; Boengiu, S., 2008 [17]).

The present study aims to quantify the variations of monthly and annual flows registered at Dragoia hydrological station (Desnățui River) between 1964 and 2011, from a statistical perspective (Pearson III statistical test, the module coefficient, determining polynomial tendencies). It is important to mention that the upper basin of Desnățui is characterised by an intermittent flow which, during periods of abundant precipitation, often generates flash floods.

The upper basin of Desnățui is situated in the South-western part of Romania (Figure 1), and it includes the South-Eastern part of the Bălăcița Piedmont, a subunit of the Strehaia platform. It occupies an area of 216 sq km out of the total area of 325 sq km representing the whole basin of Desnățui, it is oriented on an NW-SE direction, (up to the vicinity of Fântânele Reservoir) and, through its network of tributaries, meets the Danube [17].

The reason why we used the term ”river basin” instead of ”watershed” is the hydrological use of this study, due to the fact that we tried to cover the water flow aspects, not the influence of the geomorphological features on the discharge. Moreover, the river basin, in general, is the basic unit of all hydrological analysis and designs thus, it is the only spatial distribution which includes within its borders all the water processes that characterize the flow.

Desnățui's sources are to be found among the few springs located in the piedmont hills in the Northern part of the Basin, but most of its waters are caused by torrential precipitations, being known as ”spring high waters”.

As far as the basin geomorphology is concerned, it can be characterized as an extensive floodplain (in the southern part) and it has the aspect of low hills (in the North, at the top of the valleys). The altitude varies from S-SE to N-NE between 75 and 305 metres, with an average value of 170 meters.

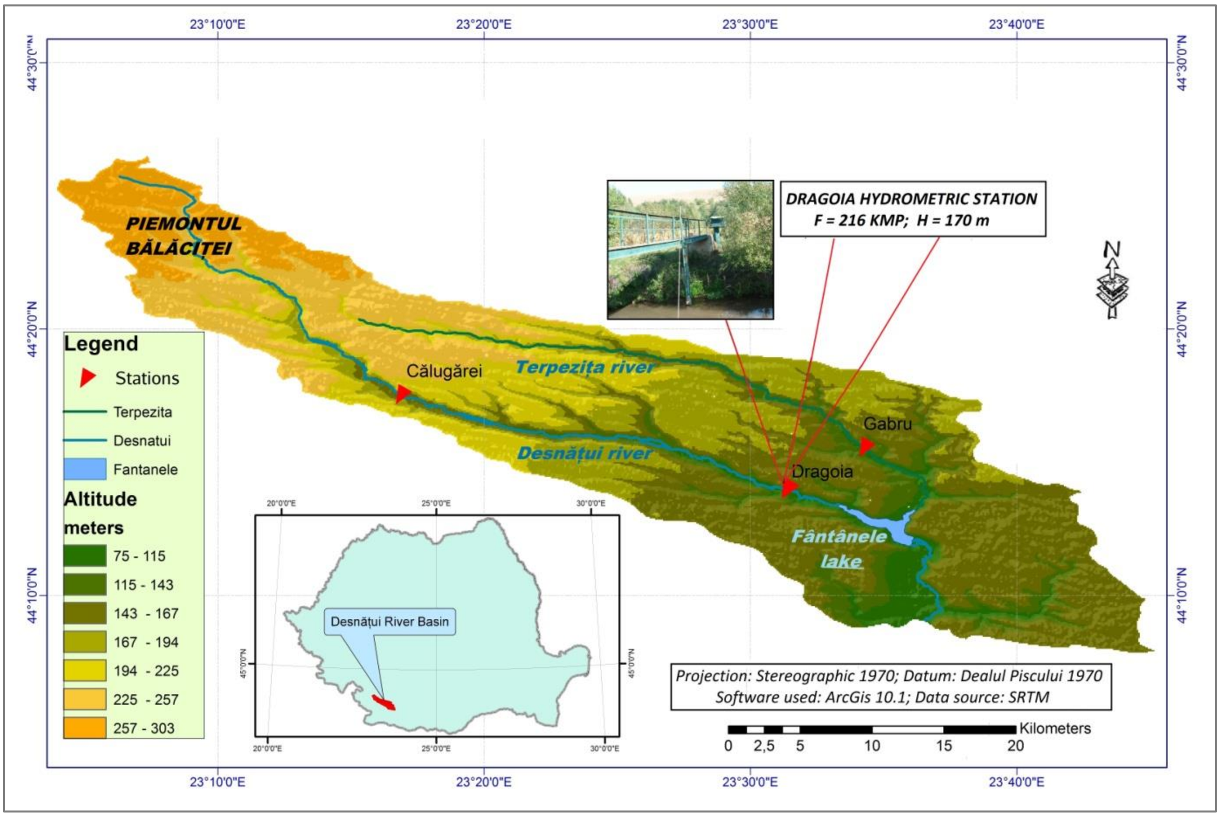

Figure 1. The location map of Desnățui's river basin in Romania and the position of the hydrological stations

2. DATA AND METHODS

In order to achieve this study, hydrological and meteorological data sets from 1964 to 2011 have been used, offered by the Jiu River Basin Administration (for Dragoia hydrometric station) and by the Regional Weather Centre Craiova (for monthly precipitation data).

The statistic analysis of Desnățui's upper basin includes several stages (Figure 2): the data classification, data editing and processing, generation of the correlations through the use of the module coefficient, the yearly distribution of the maximum flow – Pearson III, the variation of the average monthly flow correlated with the average monthly values of precipitations for the studied interval.

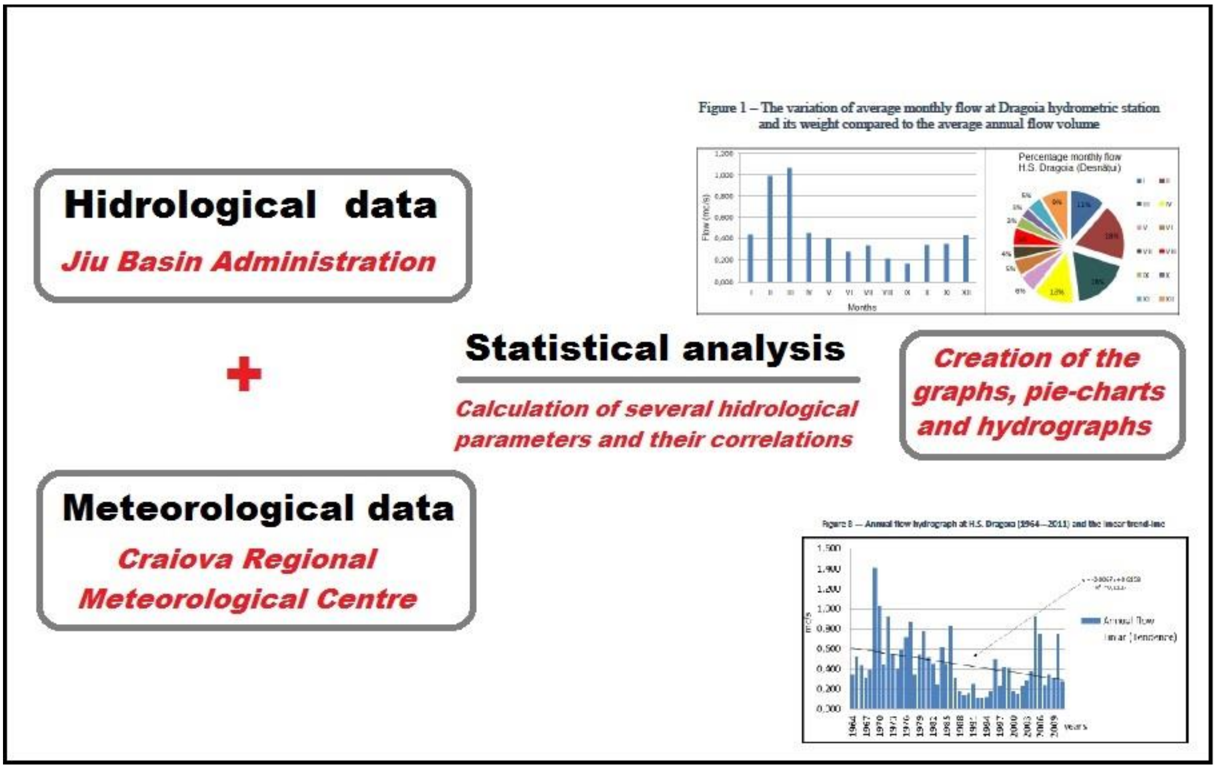

Figure 2. Conceptual schema of the method used in the study

It is also worth mentioning the cartographic method used for mapping the hydrometric stations in the upper basin of Desnățui. The software used for mapping were ArcGis 10.1 and Global Mapper 11, while the software used for the mathematical calculations was Microsoft Excel.

The statistical inference used in the study proved to be robust, because of the lack of daily hydrological data. Instead, we used only mean monthly and annual discharge data, available for Dragoia gauging station from 1964 to 2011. Besides the basical interpretation of simple charts obtained after ordinating and representing the data, we evaluated the return probabilities of certain hystorical discharge values and we tried to find the best polynomial tendence for moving mean annual flows.

3. RESULTS AND DISCUSSIONS

3.1 The correlation between the precipitation regime characteristic for Desnatui's river basin and the average monthly flow averaged for the 1964-2011 interval at Dragoia hydrometric station

Desnățui's flow in its upper sector is influenced by both the solid precipitations regime during winter (especially by snowmelt) and by the liquid precipitations regime during summer and autumn.

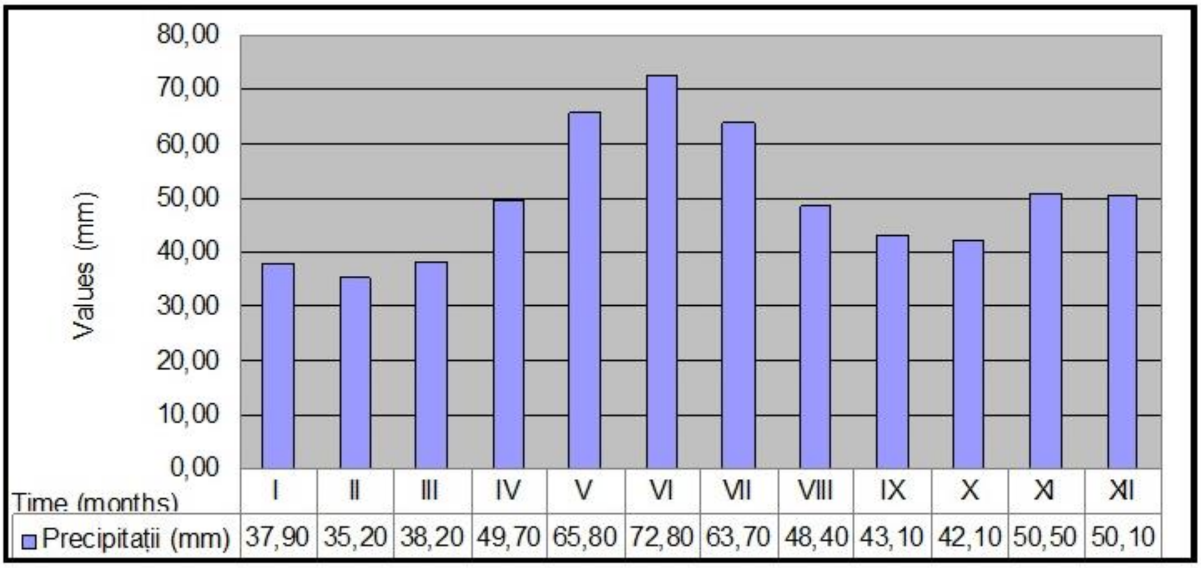

Figure 3. The distribution of monthly values for precipitations at Craiova W.S.

According to the weather data provided by the Craiova weather station for the analysed interval (1964-2011), the rainiest month is June, with a maximum of 72.8 mm, and the driest one is February, with 35.2 mm (Figure 3). The monthly flow regime thus suffers important variations, confirmed, among other elements, by the average monthly volume (Figure 4).

The connection between these two graphs is not very good, as there are differences between the time when the highest rainfall and monthly occur. The explanation for this inadvertence is that, although the summer is characterized as being the wettest season, especially in the transition weeks between May, June and early July, the evaporation exceeds the capacity of rivers to accumulate enough water for their discharge. The consequence is that summer months are among the most critical ones as river regime regards, being known for what we call ”étiage discharge” periods.

In contrast, in the first months of the year, the discharge attains its maximum values, although the period February – April is barely the second one during the year as rainfall rates and quantity regards. This happens due to the high intake of humidity in the watershed, as a sum of precipitation and snow melt inputs.

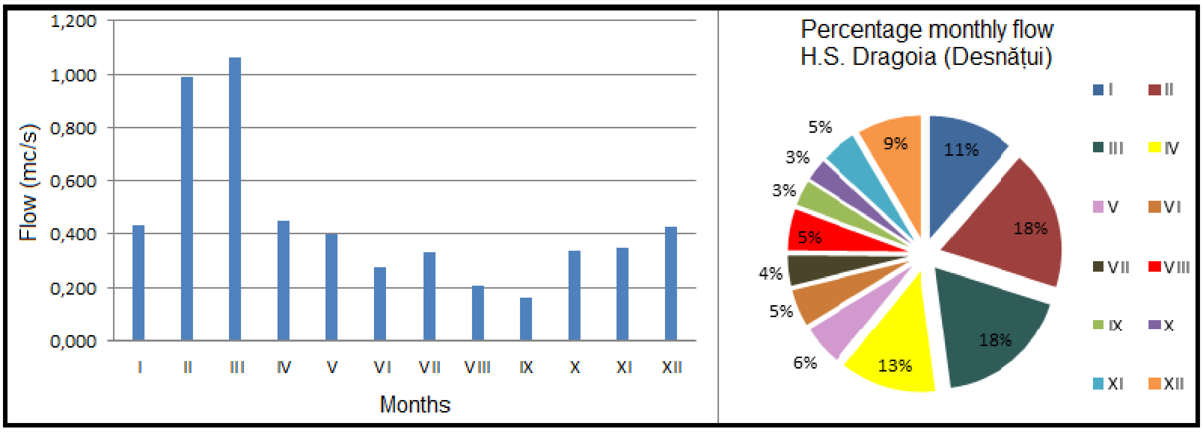

Figure 4. The variation of the average monthly flow and the representation, as percentages, of the average monthly volume at Dragoia Hydrometric station (1964-2011)

The chart presented above (Figure 4) shows that on Desnățui river (Dragoia station), record flows are registered in February and March (more than 1 m^3/s), which is the interval when ”high spring waters” occur, at the end of winter and beginning of spring.

In this context, it is possible to distinguish, at first glance, an inconsistency between the amount of precipitation recorded in February and the flow regime for this month (0.9 m^3/s, 18%). The explanation is given by a number of geomorphologic (lithology, slopes, exposure, profile curvature) and hydro-geomorphologic factors (shape of the basin, water's capacity to infiltrate) that are not the object of this study.

Beginning with June, although the rains are sufficient, their regime is torrential and they are countered by the increase in evaporation. Thus, the percentages decrease, and the lowest values are recorded in September and October. Also, the period between October and the beginning of January is the second high-waters period during the year.

3.2 Determining the tendencies of maximum, average and minimum flows

The probability of a random value can be expressed by the value of Skew coefficient (Cs), which is -0.15. It is defined as a measure of the extent to which a probability distribution of a real-valued random variable "leans" to one side of the mean [11]. In our case, it is negative, meaning that the mass of the distribution is right skewed in the Figures 5 and 6. Thus, it is possible to determine a linear tendency with different evolutions depending on the type of flow: average, maximum or minimum.

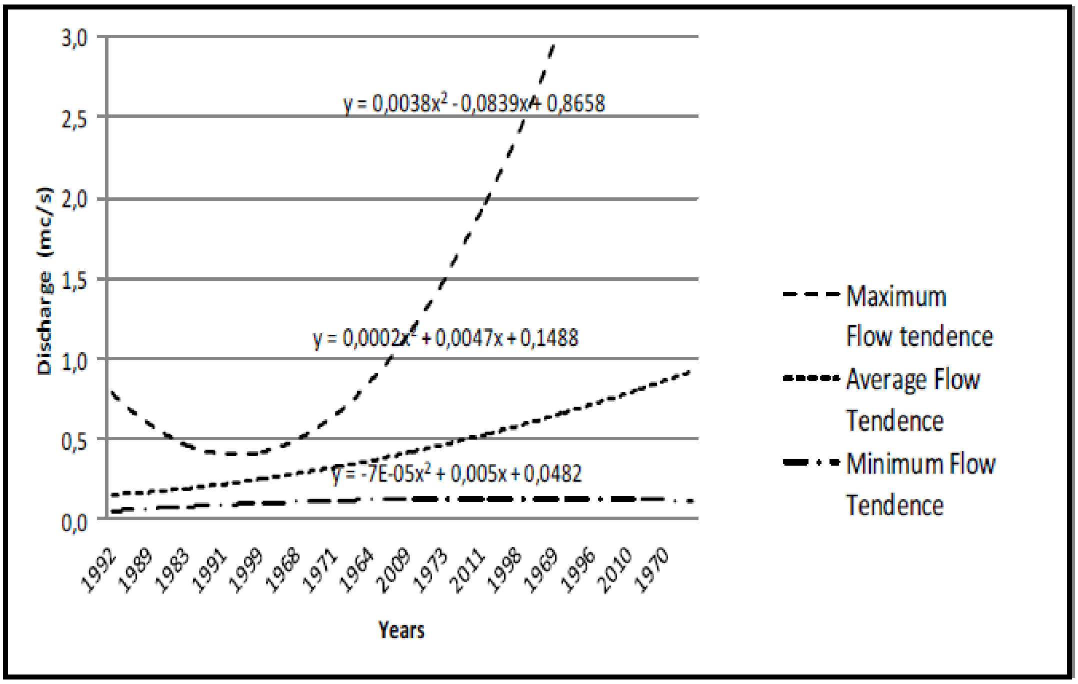

Figure 5. Statistical evolution of the average maximum and minimum flow

(Data source: ABA Jiu- 1964-2011)

Whereas, for minimum flows, the linear tendency is almost parallel with the Ox axis, showing a very small variability from one year to another, the semi-permanent character of the discharge regime becomes even more apparent as we begin to encounter the maximum flows. Therefore, the tendency of the annual averages of flows is that of a slight increase over the first part of the interval, followed by a stronger increase towards the end of the analyzed period, when the climatic changes in the general synoptic context occur.

3.3 Pearson III distribution of the maximum annual flow, its return time and probability

The maximum flow dataset beneficiated from the implementation of Pearson III probability distribution, defined as a gamma or chi-squared distribution [13]. In hydrology, it estimates the return period of certain historical discharge values, their probability to occur and their frequency, from a range of ordered discharge values. Mathematically, the Pearson III method uses a logaritmic approximation, its accuracy increasing with the interval taken into consideration [12]. The results are shown in the Figure 6 and can be further understood in detail by reading Table 1.

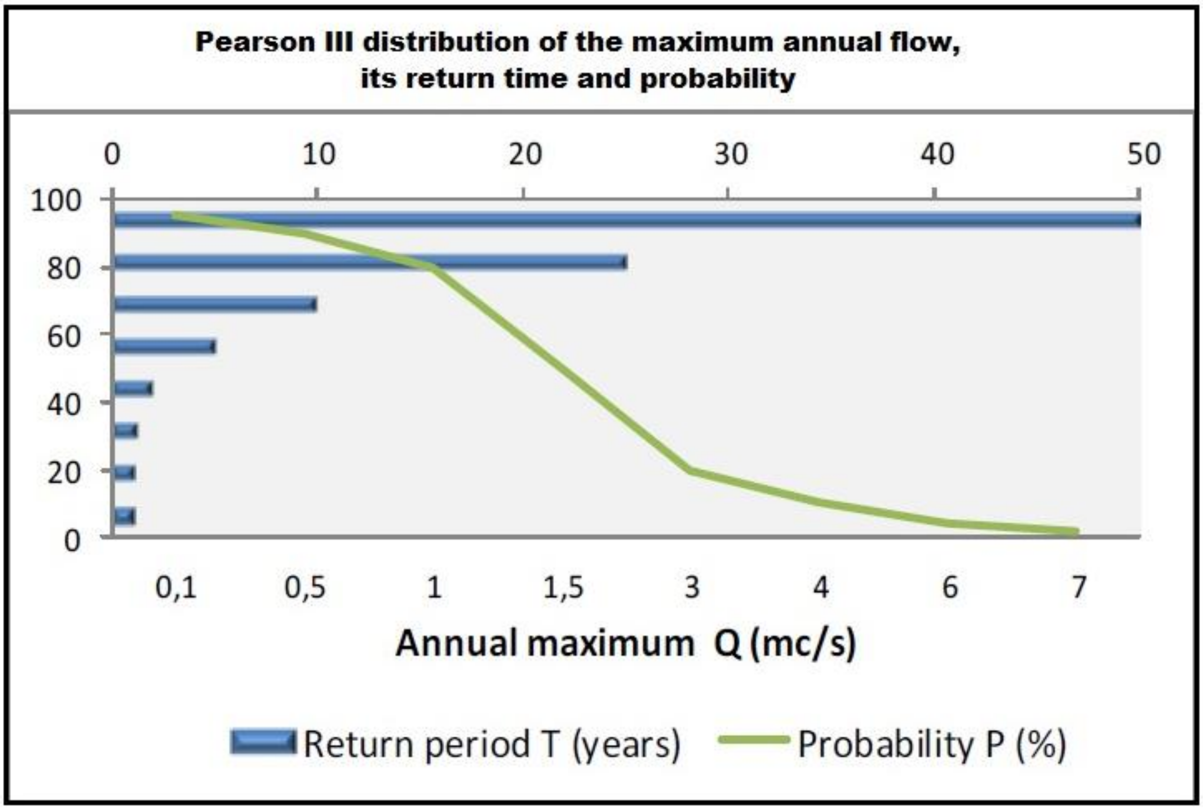

Figure 6. Pearson III distribution of the maximum annual flow, its return time and probability

It is to note that the small values of the flow (lower than 1 m^3/s) tend to equalize their return period, having an average of 35 years, while as the mean annual flow gets higher, the values of the return period become more and more distant from the average.

Table 1. Pearson III statistical test results

Results of the Pearson III statistical test

Return period T (years)	*Probability P (%)*	*Frequency factor K*	*y = log (Q)*	*Discharge Q (m3/s)*
1,05	95,2	-1,687	-0,562	0,1
1,11	90,1	-1,296	-0,409	0,5
1,25	80	-0,833	-0,228	1
2	50	0,025	0,108	1,5
5	20	0,848	0,431	3
10	10	1,264	0,594	4
25	4	1,697	0,763	6
50	2	1,971	0,871	7

Significance (Table 1): $y = \log(Q)$ $K = f(T, C_{sy})$ $y = y_{ave} + K_{sy}$ $Q = \log^{-1}(y)$

Another remark that can be made is that the probability of occurrence over 80% entirely corresponds to the discharge values of 1 m^3/s or less. At the same time, the return period for the mean annual flow oscillated between 1.05 and 50 years (for the maximum mean annual flow of 7 m3/s), which confirms the semi-permanent hydrological regime of the flow in the upper basin of Desnățui river and the predominance of low mean annual flow values.

3.4 The investigation of the flow variability through the specific liquid flow and the module coefficient

The specific liquid flow represents the thickness of the uniform layer of water distributed on the surface of the basin in a specified amount of time [14]. The formula is based on the liquid flow, in relationship to the surface of the basin upstream of the station where the measurement was taken, following this formula: q[l/s.km2] = 1000. FDragoia = 216 kmp.

Figure 7 provides valuable insight in the way the mean annual flow is distributed on the entire watershed.

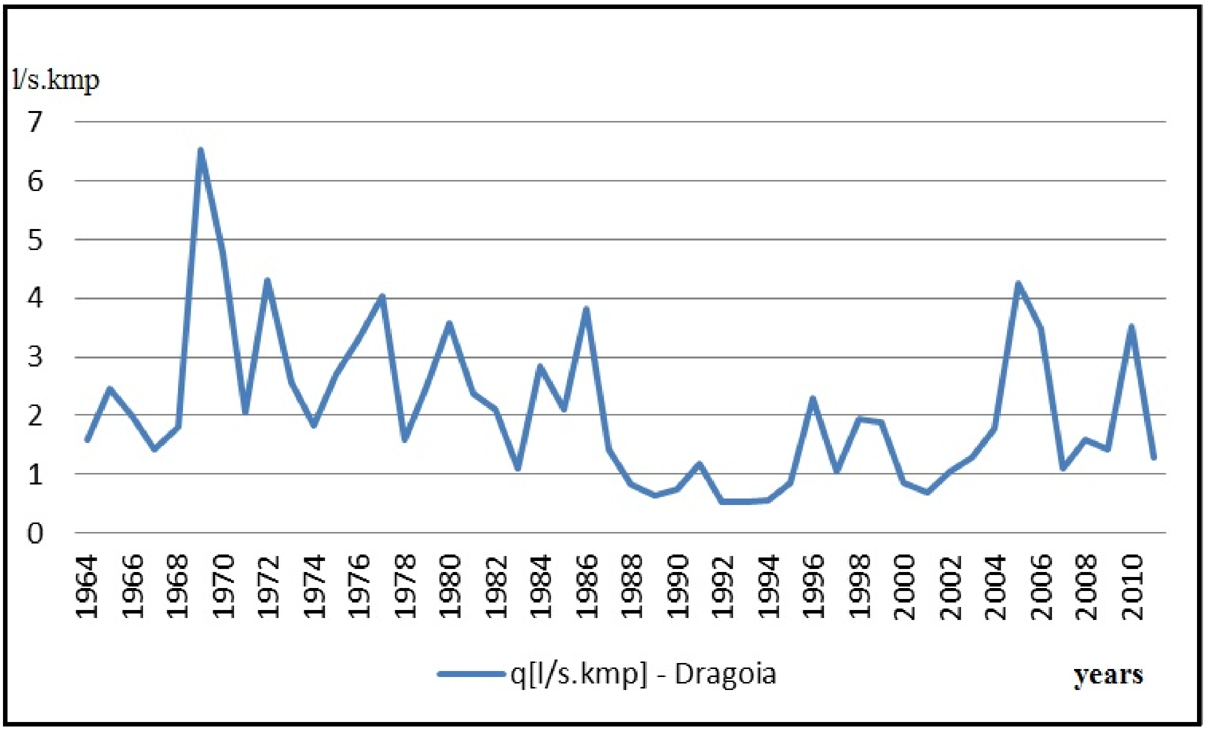

Figure 7. The variation of the specific liquid flow at Dragoia hydrometric station - Desnățui river (Data source: ABA Jiu – 1964 – 2011)

Although it is directly proportionate with the mean annual flow, its values, as reported to the surface of the basin are more subtle in describing the tendences of the river discharge, but most important, in making comparisons between river basins having different orders of magnitude. After a first eye-view of the specific liquid flow distribution, what strikes is its fluctuation on short time intervals.

The analysis of variance with specific liquid flow focuses in this context on answering one question: is the variability in the sample means so large that it seems unlikely to be from chance alone? This question is different from earlier testing procedures, since we simultaneously considered that the variability of mean annual flow and, more specifically, its highest peaks, can be put only on the rainy years which generate the outmost flash floods and, along with them, a massive increase in the mean annual flow of some years. With this occasion, we are able tore-evaluate whether the flow regime in the analyzed interval (1964-2011) differs more than we would expect from natural variation.

The module coefficient offers information on the variation of the discharge over time [14], according to the formula $K = Qi/Qo$. To note that in the years when flash-floods occurred (1970, 1995 and 2005-2006) - Table 2, the coefficient of the flow was several times greater than the average (Figure 8).

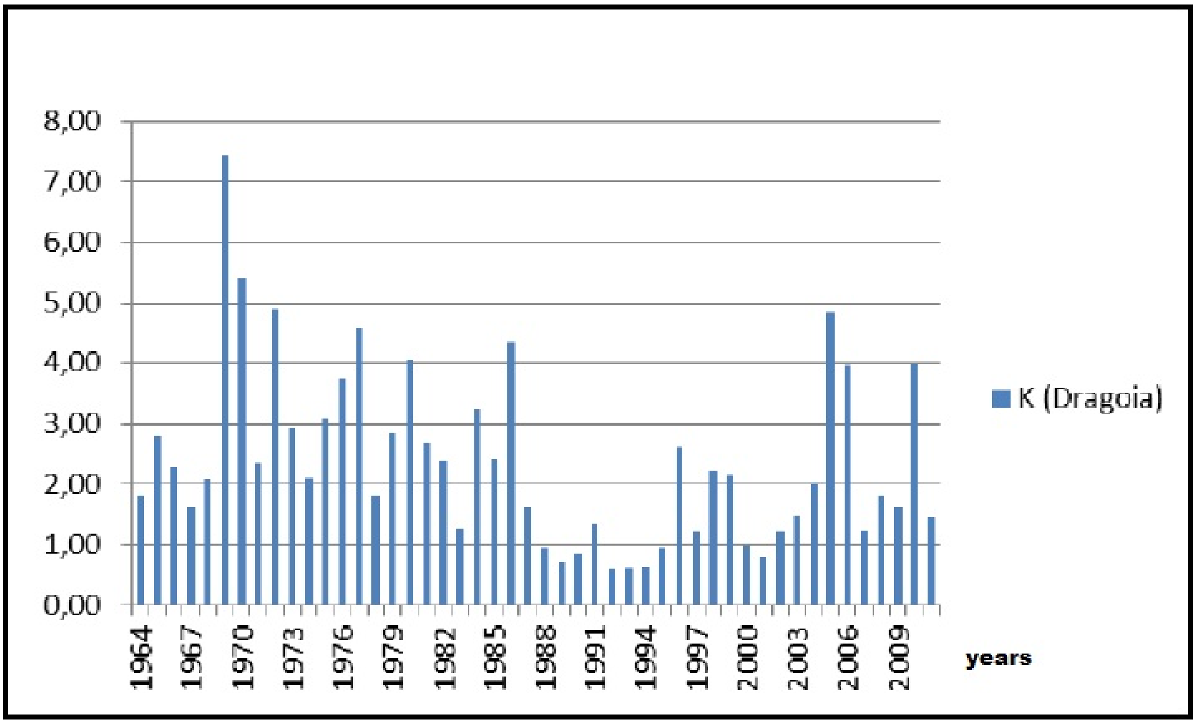

Figure 8. Module coefficient at Dragoia hydrometric station (1964-2011)

This method of representation of this parameter derived from the mean annual flow values is frequently used in statistical analysis, as it proves to be more supple in correlating the multiannual mean flow with the annual mean flow values, but also in showing the deviations of some years from the average. One may distinguish a smaller deviation from the mean for the minimum module coefficients, from the one appearing in the years with maximum mean flow.

3.5 Assessing the contribution of singular floods over the years on the rapid increase of the mean annual flow values and the establishment of appropriate tendencies to characterize the interannual flow variability

In our attempt to explain the variability of interannual discharge on Desnățui river, we also headed our perspective towards the central limits theorem [18], which states that whenever we deal with a small sample size, the normal approximation may not be proper. On the contrary, as the sample size gets larger, the normal approximation improves. Based on these findings, we used as sample data the three most outstanding flash flood events on Dragoia river, the events from February 1970, November 1998 and April 2005.

Generally speaking, the box plot method (Table 2 and Figure 9) proved to be one of the most suitable to draw the differences of flow amplitude between these three sample hydrographs.

Table 2. Box-plot construction background values

	First quartile	Superior adjacent value	Inferior adjacent value	Third quartile	Median
1970	2.2	5.71	0.41	4.23	3.47
1998	0.32	25.8	0.015	23.85	4.2
2005	0.33	14.3	0.272	8.17	1.32

There are some prominent outliers visible in the infield, which particularly arrive when there is a strong skewness characterizing the distribution of discharge values in a flash-flood hydrograph of a semi-permanent river.

For the first year of major deviation of peak flow from the median of 3.47 m^3/s (Figure 9), there are five outliers, ranging from 7.9 m^3/s to 19 m^3/s. In this first box plot, one can easily note that the interquartile interval is the narrowest one, comparing to the others, which may lead to the observation that the flash-flood from February 1970 had a descend slope many times longer than the growing period.

The second flash-flood that we analyzed was the one from November 1998, which by far could be defined as the least ample one, showing a difference between the peak flow and the lowest value of less than 25 m^3/s. It is also emphasized as the only flash-flood event with no outlier.

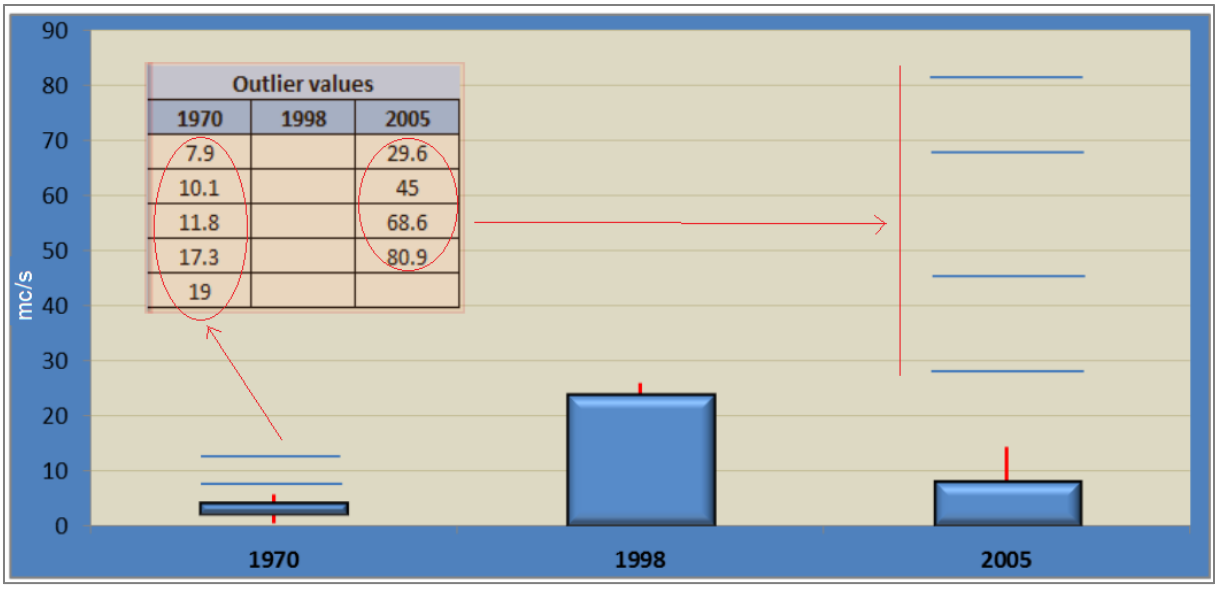

Figure 9. Side-by-side box plot of the three most powerful flash-floods occuring on Desnățui River (1970, 1998, 2005)

Last but not least, we introduced in the box plot the flash flood event from Aprilie 2005, thus obtaining a complete image of the extreme hydrological events occuring in the research interval (1964 – 2011 – for the mean annual flow, followed by the three years with flash-floods uniformly distributed). By examining the last data set and box plot, it is evident that this extreme hydrological event plays an important role in establishing the range of annual flows, as its recorded values are somewhat historical.

In this consideration, the four outliers affect the distribution of the sample mean and suggest that the hydrograph of this flash-flood event is very strongly skewed. To exemplify, its minimum value is 0.088 m^3/s, while its maximum one is 80.9 m^3/s, thus 1000 times higher than the value bordering the beginning of the hydrograph, but also more than 70 times higher than the median of 1.32 m^3/s. This flash flood event presents the most distant outliers from the median, but at the same time they are almost equally distanced one from another, suggesting a step by step decrease slope of the hydrograph.

3.6 Moving average using 5 years—quantiles for determining the best polynomial tendence to characterize the variability of the annual flow.

Moving mean is a method for determining and extracting trend of time series [13]. We assumed that the confidence interval which can best define a variability neither exaggerated as length regards, nor too insignificant, would be 5 years. We took into account this interval by noting that the samble mean is changing each five years and that the multiannual variability of flow at Dragoia hydrometric station presents homogeneous cycles of aproximately 5 years.

The graphical representation (Figure 10) reveals variations on different time intervals and analyzed parameters can be used to determine the polynomial degree to adjust the series.

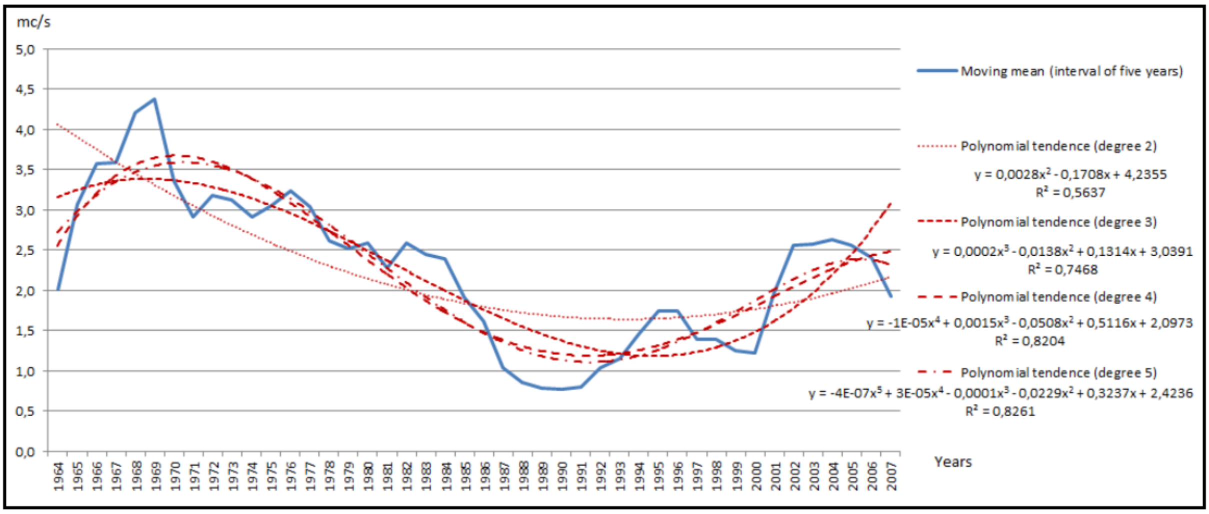

Figure 10. Temporal variation of flow at Dragoia h.s. (1964-2011) and the representation of moving means on intervals of 5 years

From the calculations we applied to each sequence of average flow corresponding to five-years interval, we could notice that, as the degree increases, the polinomial tendence becomes more accurate. The degree of ”4” is the most compelling, as it does not exaggerates the trend—line but, at the same time, it considers the small fluctuations which last less than a quantile of five years. The trend—line shows that the analyzed period is composed of two sub-intervals, the first one being characterized by a general rising of the annual flow, whereas in the second interval (after 1992) the values are in a general trend of increasing, but not reaching the peak mean values from the first years.

All in all, the results indicate a decreasing trend from average values greater than 0,6 mc/s to values two times lower in the last 10 years. Taking into account the agricultural destination of the floodplain along the main river, we assume that the different statistical approaches carried out in our research can contribute to a better understanding of Dragoia hydrological regime in relation to cultivation practices. Moreover, the effects of the average runoffs and the return periods of maximum and minimum discharges in the study basin were not discussed before among scientists, meaning that our study may prove its effectiveness for the future plans of agricultural land usage with respect to surface resources.

6. CONCLUSIONS

The graphical results and the statistical methods applied on the average, minimum and maximum annual and monthly flows show the fluctuating character of the discharge, which depends on the amount of precipitation registered. It is a strong correlation between flow size and the return period, whereas the probability to occur varies inversely proportional with the size of the flow.

A compared analysis of the charts reveals information on the dry and rainy years, some of them (the excessively rainy years) being found both in the elevated values for the volume of water discharged and in the data on flash-floods. It is also possible to see how a single flash-flood influences the discharge over the course of a year, which confirms that these extreme hydrological phenomena can sustain the discharge for up to 100% during certain periods.

The general tendency for the maximum flow over a year is to diminish, while the minimum flow has a smoother distribution and tends to remain at the same low values as in the first years of reference.

We may generalize that the interannual discharge in the upper basin of Desnățui river, based on the available hydrometric data for Dragoia station, is constantly decreasing, moreover in the last two decades, although the flood events show an increase in intensity, amplitude and volume. Also, the geographical space including the upper basin of Desnățui river is one with continental character regarding rainfall and discharge regime, the three most powerful flash floods spread all over the year, in all seasons except for the winter, confirming this hypothesis and the complexity of water input in the basin.

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