"BABEŞ-BOLYAI" UNIVERSITY OF CLUJ-NAPOCA
FACULTY OF GEOGRAPHY

PHD. THESIS

EXTREME HYDROLOGICAL PHENOMENA IN ROMANIAN PLAIN BETWEEN OLT AND ARGES RIVERS

-ABSTRACT -

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Key-words: hydrological risk, highflood, drought, damages, impact, prevention.

INTRODUCTION

The main goal of this thesis is to identify and to analyse two of the extrem hydrological phenomena specific to the Romanian Plain between Olt and Arges rivers floods and drought.

In order to reach this objective, after studying the scientific literature on this topic, special research was made on the two phenomena using statistical data recorded by the specialized institutions and talking to the people in the area. Some case studies were presented in order to prove the severity od the events, not only in statistical data, but also in their impact.

The study is devided into six chapters and it ends with conclusions, references list and apendices.

After a short history of the research on the evolution of the Romanian Plain between Olt and Arges rivers, some special aspects like genesis, development, climate and relief types as well as main hydrological features were presented (chapter 2). It worth mention that most part of the studies did not consider floods or drought.

The main climatic and hydrological features of the Romanian Plain between Olt and Arges are the subjects of a special chapter (chapter 5), because we considered that they are very important and necessary for the understanding of the floods and drought evolution.

The most important part of the thesis is covered by the last chapters dedicated to the floods and drought (chapter 6).

Floods were analysed both considering preparing factors and tighering ones. Data of five weather stations were anaysed in order to identify the triggering conditions, while data from 12 hydrological stations were used to identify and analyse the parameters of the floods. Finally the impact of the floods including economical, social and ecological damages were identified.

Drought phenomenon is affecting nowadays, very large areas all over the world. E. Bryant (1992), based on the multi-criteria hierarchy, considered it as the most important hazardous phenomenon in the world. Many scientific papers and projects had as their main goal to study the phenomenon in different regions of the globe (Assessment of the Regional Impact of Droughts in Europe, 2001, Sectorial Impacts of Drought and Climate Change, 2008, Evaluation of Arizona Drought Watch: The State's Drought Impacts Reporting System, 2009, State Drought Planning in the Western U.S.: A Multi-RISA-Agency-NIDIS Collaboration, 2010).

In Romania, the most affected areas are located in the south and in the eastern parts of the country (Moldovan, 2003).

Based on a high number of factors, drought events – atmospherical, pedological, hydrological, mixte – have an extremely negative impact: ecologic (deterioration of agrcultural terrains, the reduction of the biological potential of soil etc.), economical (the ruduction of the agricultural crop associated to the food security of the population, the decreasing of the hydroelectric energy, problems in water supplying), social (poverty, epidemics).

The section dedicated to drought is devided into eight subchapters: the first three of them present theoretical aspects of the drought concept, classification of drought events, short presentation of the generating factors as well as the description of the main drought types (atmospherical and hydrological (streamflow drought)).

In this study, we detailed two extreme hydrological phenomena: floods and droughts. Floods represent a special experience, even it is not a pleasant one, but a traumatic one and with terrifying results for the population affected. They are always a threat for the inhabitants of the prone settlements. At the same time, drought events, even they are charged as less dangerous phenomena compared to floods, have serious enough consequences to be treated as important hazards by population and by authorities.

GEOGRAPHICAL LOCATION, LIMITS AND TERRITORIAL SUBORDINATION ELEMENTS

The studied region is known also as Teleorman Plain. It has a total surface of 12.490 km^2, representing 26,99 % of the plain areas of the country. The region is also named as Central Romanian Plain, Western Muntenia Plain, Arges Plain ((Mihăilescu, 1966) etc. Reccently, it has been named as Teleorman Plain according to the name of the river that crosses it from North to South (Posea and Badea, 1984, in Geografia României, 2005). In the area, there are three hydrographical basins: Vedea, calmatui and Neajlov with a total number of 90 rivers.

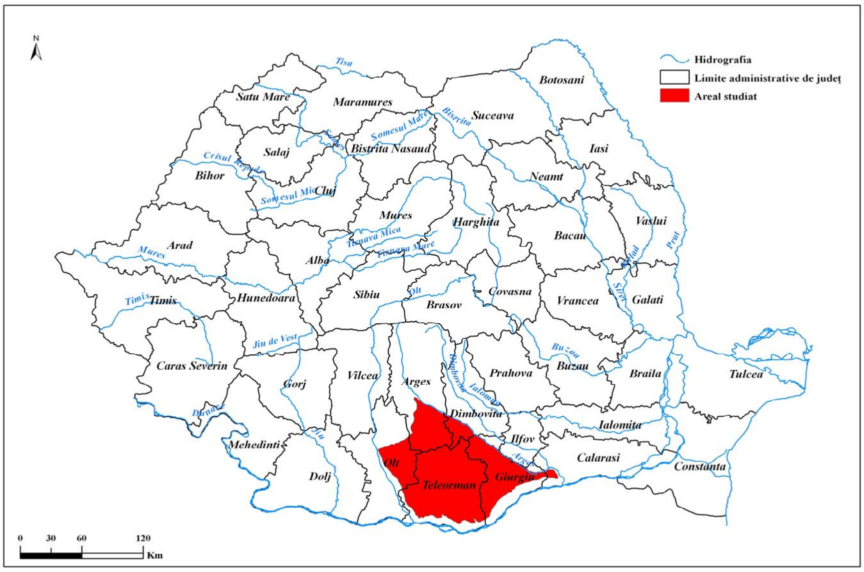

Figure 1. Geographical location of the studied region

METHODS

In order to determin trends in the time series, Mann-Kendall test and Sen's slope estimates were used. The methods accept missing values and the data do not have to obey any particular distribution . Sen's slope is not greatly influenced by singular errors in the data series. To calculate trends, the MAKESENS soft was employed.

HYFRAN soft was used to compute the probability of occurence of different discharge flows. For each river, it was chosen the probability aproximation low that fitted the best to the data series.

To analyse precipitation data sets of the five weather stations considered (figure 2), the weighted standardized precipitation anomaly was used in order to identify rainy or dry periods.

To draw the flood hydrograph and to calculate the single floods parameters, CAVIS software was used. It is a Windows application with two modules, one for management of the input data and the other for the calculation of the single floods parameteres.

The threshold method as described in the European Project ARIDE was employed to identify the duration, the severity and the occurance period of the streamflow drought events.

CHARACTERISTICS OF THE MAIN CLIMATIC ELEMENTS AND OF THE RIVERS STREMFLOWS IN ROMANIAN PLAIN BETWEEN OLT AND ARGES RIVERS

Data

In order to analyse the extreme hydrological phenomena in the Romanian Plain between Olt and Arges rivers, we used data recorded in five weather stations and 12 hydrological station located in the area. The climatic data cover 43 year (1965-2007) and they were provided by the European Climate Assessment (Klein Tank AMG et al., 2002) and by Meteorological National Administration.

As climatic parameters, mean monthly, seasonal and annual temperatures, monthly and annual precipitation together with the monthly maximum amount recorded in 24 h and mean thickness of the snow layer were analysed.

For the streamflow analysis, the mean monthly, annual and multi-annual discharge flows were considered. For the analysis of floods and drought events, daily discharge were used.

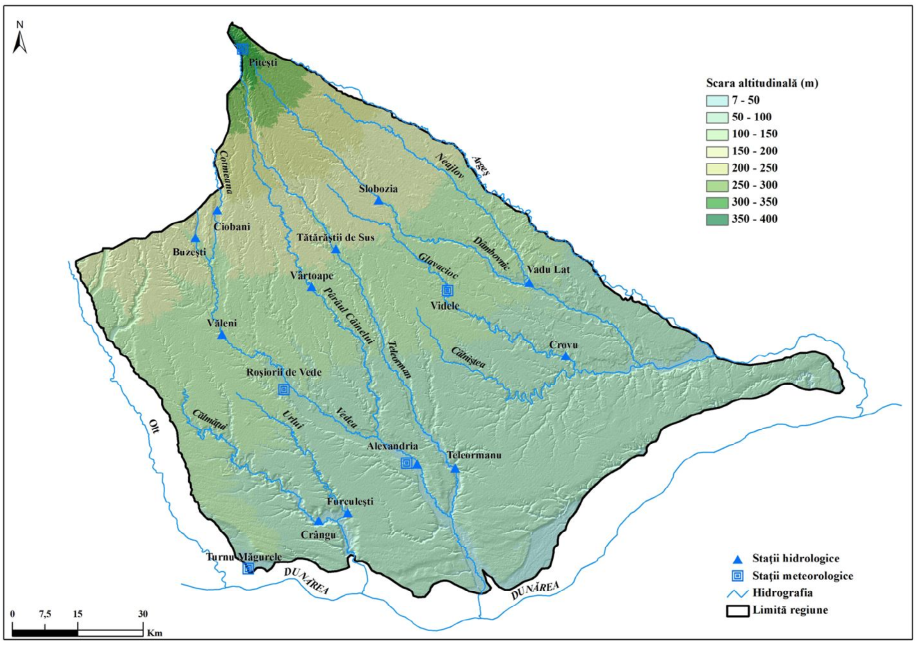

Figure 2. The hydro-meteorological measurements network in Romanian Plain between Olt and Arges

General climatic features

Air temperature

Air temperature has a simple variation, with minimum values recorded in January (-1.1°C ....-2.2 °C)and maximum values in July (20.8 °C....23.3 °C) (table 1). The mean annual value increses from north to south and respectively from 10.2 °C, recorded in Pitesti, to 11.4 °C, at Turnu Magurele.

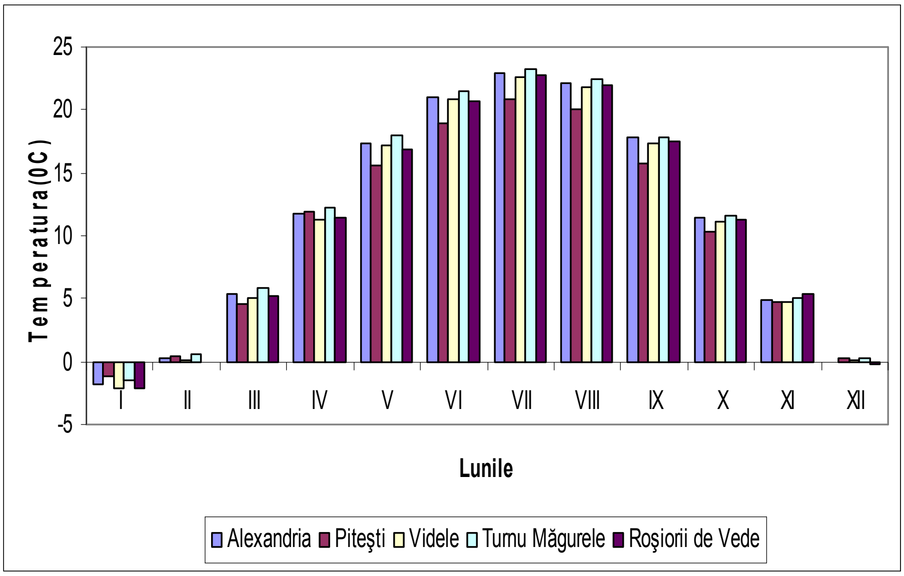

Figure 3. Mean monthly air temperature (1965-2005), (°C)

Regarding trends of air temperature, one can notice a general increasing trend in the area for the most data sets. Thus, for 11 of the time series, there are increasing trends for all weather stations. For annual, summer and summer months values, the trends are also statistically significant (table 1). For September, December and for the winter season, for the most locations, the slopes were negative. For April and November, some weather stations recorded stationary trends.

Table 1. Trends of air temperature (ºC/decade)

Station	Piteşti		Videle		Roşiorii de Vede		Alexandria		Turnu- Măgurele	
Series	Q[1]	SS[2]	Q	SS	Q	SS	Q	SS	Q	SS
J	0,696	*	0,265		0,213		0,322		0,212	
F	0,354		0,315		0,289		0,366		0,298	
M	0,344		0,304		0,258		0,300		0,203	
A	-0,067		0,000		0,000		0,069		-0,056	
M	0,266		0,257		0,303		0,290		0,140	
J	0,667	***	0,636	**	0,614	**	0,750	***	0,442	*
J	0,552	**	0,500	**	0,500	**	0,538	***	0,452	**
A	0,553	**	0,500	**	0,500	*	0,545	**	0,467	*
S	0,000		-0,133		-0,131		-0,080		-0,200	
O	0,237	+	0,196		0,200		0,188		0,226	
N	0,000		0,000		0,050		0,000		-0,065	
D	0,200		-0,086		-0,127		-0,155		-0,167	
Annual	0,242	*	0,195	*	0,159	+	0,187	+	0,151	+
DJF	0,333		0,133		-0,037		-0,033		-0,031	
MAM	0,159		0,176		0,146		0,202		0,093	
JJA	0,532	***	0,504	***	0,497	***	0,539	***	0,444	**
SON	0,061		0,000		0,012		0,000		0,025	

[1] – Average slope [2] – Statistical significance: α= 0.1; * - α=0.05; ** - α=0.01; *** - α=0.001.

Precipitation

The monthly amount of precipitation respect the low of the temperat continenetal regime, with maximum values recorded in summer months and minimum values specific to cold period of the year.

There is a general decreasing trends of precipitation amounts in the area. Thus, for the 61.18% of the analyzes data sets, the trends are decrasing (table 2). Among them, only 10 % (8 data sets) are statistically significant with different confidence level varing from 90% to 99%.

It worth mention that, for all weather stations considered, the annual amount of precipitation have decreasing trends with quite high value: 30 mm/decade or even higher.

The increasing of the precipitation amount specific to the autumn months is very low compared to the decreasing trend specific during summer and it can't balance the accumulated deficit.

Table 2. Trends of the monthly, seasonal and annual precipitation (mm/decade)

Station	**Pitești**		**Videle**		**Roșiorii de Vede**		**Alexandria**		**Turnu-Măgurele**	
Series	Q[1]	SS[2]	Q	SS	Q	SS	Q	SS	Q	SS
I	1.029		0.145		-1.854		-1.777		-2.396	
F	-1,207		-2,297		-5,649	*	-4,586	+	-4,125	*
M	1,471		2,459		1,025		0,540		-0,387	
A	1,365		1,812		-0,336		0,364		0,739	
M	-2,117		0,689		-3,520		1,386		-2,819	
J	-10,031		-2,141		-5,319		-3,209		-7,523	+
J	3,370		-0,528		-1,069		-5,101		-0,498	
A	-3,325		-7,933		-1,818		-13,976	**	-5,426	
S	5,458		4,855		3,639		6,214	+	6,739	
O	5,697		3,240		3,074		1,986		2,927	
N	-1,125		-2,012		-4,637		-2,766		-4,390	
D	1,146		2,244		-0,400		-0,602		-1,519	
Annual	-11,682		-8,943		-22,511		-30,459		-30,000	
DJF	2,889		-3,164		-9,002		-11,600	+	-12,216	+
MAM	0,825		3,277		-2,895		1,931		-3,690	
JJA	-9,010		-10,906		-6,750		-24,458	+	-14,865	
SON	8,063		9,456		4,892		7,638		8,139	

[1] – Average slope

[2] – Statistical significance: α= 0.1; * - α=0.05; ** - α=0.01; *** - α=0.001.

Snow cover

The depth of the snow layer is one of the most important climatic parameter together with the total amount of liquid precipitation for the analysis of the flood occuring at the end of the winter or at the biginning of the spring.

In the Romanian Plain between Olt and Arges rivers, mean depth of the snow cover were analyzed from November till March (figure 4).

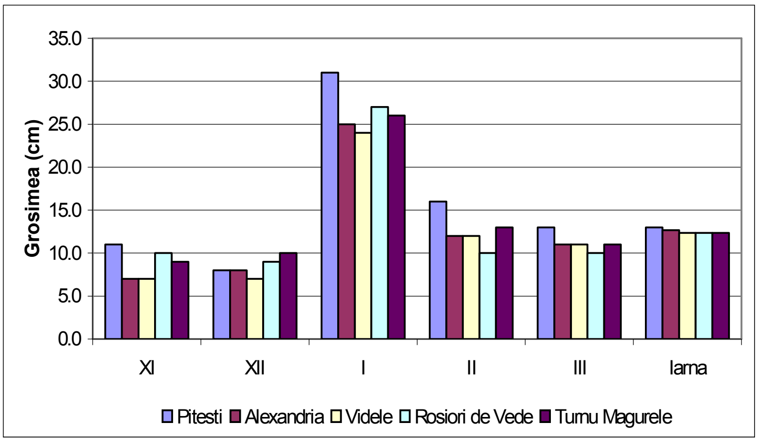

Figure 4. The mean depth of the snow cover (cm)

Hydrological features of stream flow in Romanian Plain between Olt and Arges

General features of the area

The segment between Olt and Arges rivers of the Romanian Plain is characterized by a flat plain relief, excepting the northern part where it is a hilly plain (Pitesti Hilly Plain).

The river network in the analyzed area has a mean density of 0.36 km/km^2, and varies from 0.67km/km^2, in the higher part (in the North) to 0.57 km/ km^2 in the central area and to 0.03 km/ km^2, in the lowest areas (South).

The shape of the hydrographical basins is evenly developed from NW to SE along the rivers. The shape has an important influence on the stream flow.

In the area, there are 130 permanent and non-permanent antropogenic water bodies, especially in the Vedea river basin, generally with an economic use.

The human interventions in the natural landscapes (ponds and lakes used for agriculture, for fishing, for flood flow mitigation, for water supply, for irrigation) generates changes in the natural regim of the rivers strem flows.

Multi-annual variation of the stream flow

The water from the rivers comes from the surface waters as well as from the underground waters. Each of those sources depends of the local factors, such as climatic and soils features. Surface sources are represented by precipitation and by water cming from snow melting. In the studied region, the highest precipitation are recorded during summer and spring, but the most part of them goes to underground.

An important role in the variation of water level is played by the evaporation. It may occur over the water, soil, snow cover or vegetation and determines the decreasing of the discharge flow.

The average seasonal discharge flows are presented in table 3.

Table 3. Mean seasonal discharge flow (1965-2007)

No.	River	Measurement location	Q_0 (m^3/s)	Qmed (m^3/s) Winter	Qmed (m^3/s) Spring	Qmed (m^3/s) Summer	Qmed (m^3/s) Autumn
1	Vedea	Buzeşti	0,84	1,22	1,72	0,87	0,49
2		Văleni	4,16	5,58	5,96	3,48	2,38
3		Alexandria	7,65	10,26	10,94	5,96	4,92
4	Teleorman	Teleorman	2,78	3,38	4,42	2,28	2,48
5		Tătărăştii de Sus	3,06	3,32	3,32	2,93	0,87
6	Cotmeana	Ciobani	1,37	1,96	2,09	1,16	0,83
7	Pârâul Câinelui	Vârtoapele	2,84	2,39	2,75	0,12	0,15
8	Urluiu	Furculeşti	0,56	0,71	0,60	0,41	0,55
9	Călmățui	Crângu	1,46	1,67	1,71	1,15	1,29
10	Glavacioc	Crovu	0,83	1,08	1,10	0,62	0,77
11	Neajlov	Vadu Lat	4,29	4,73	5,19	3,92	3,76

We compared the stations where the highest and the lowest discharge flows were recorded: Alexandria, located on Vedea river and respectively, Furculesti, on Urlui river. Thus, on Vedea river, the highest discharge flow is specific to spring (10.94 m^3/s), while on Urlui, the maximum discharge was recorded during winter (0.71 m^3/s) (figure 3). The lowest flows usually record during autumn on Vedea river (4.92 m^3/s) and during summer, on Urlui (0.41 m^3/s)

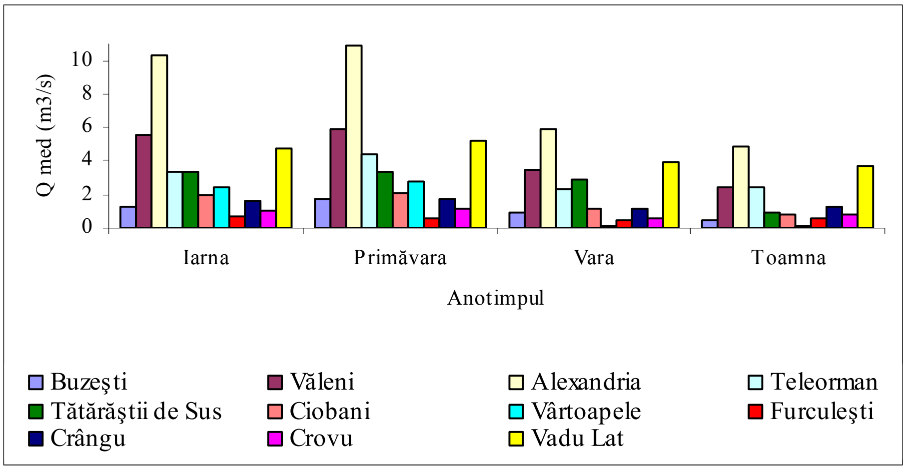

Figure 5. Mean seasonal discharge flows

Occurance probability of discharge flows

Do calculate the probability of occurance of mean annual and seasonal discharge flows the HYFRAN software was used. In order to get best aproximation, we used different aproximation lows for the rivers in the studied area: log-Pearson III, log-normal 3 parameters etc.

The maximum values of the monthly discharge do not respect any temporal or spatial rule: the maximum discharges are specific from February till July, while the minimum discharges are recorded from June till November.

Table 4. Sen’s slope of the trend for the maximum liquid discharge flow in Romanian Plain between Olt and Arges for 1965-2007 period (m^3/s*decade)

Series	**Vedea 1 (Văleni)**		**Vedea 2 (Alexandria)**		**Teleorman 1 (Tătărăştii de Sus)**		**Teleorman 2 (Teleormanu)**		**Urlui (Furculeşti)**		**PârâulCâinelui (Vârtoapele)**		**Cotmeana (Ciobani)**		**Dâmbovnic (Slobozia)**	
	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS	Q	SS
Mean flows																
J	-0.150		-0.543	*	-0.084		-0.357	**	-0.038		-0.013		-0.025		0.061	
F	**-1.327**	*	**-2.922**	**	**-0.308**	*	**-1.141**	**	**-0.090**	**	**-0.110**	*	**-0.240**	*	**-0.186**	
M	**-0.450**		**-1.550**	*	**-0.176**	*	**-0.747**	*	**-0.056**		**-0.072**	+	**-0.111**		**-0.183**	
A	-0.115		-0.500		-0.032		-0.098		-0.002		0.016		-0.081		0.123	
M	-0.404	*	-0.652	*	-0.013		-0.131		-0.006		-0.003		-0.191	*	0.057	
J	-0.526		-0.841	*	-0.052		-0.270		-0.023		-0.011		-0.145		0.142	
J	-0.308	*	-0.742	*	-0.021		-0.178		-0.012		-0.014		-0.057		0.112	
A	-0.041		0.029		0.000		-0.076		0.014		-0.011	+	0.007		0.193	
S	-0.094		-0.205		0.003		-0.095		-0.044		-0.012	*	-0.002		0.162	
O	0.043		0.003		0.020		-0.043		-0.026		-0.011	+	0.006		0.194	
N	-0.025		-0.335	*	-0.037		-0.191	**	-0.037		-0.019	*	-0.011		0.150	
D	-0.246		-0.407	+	-0.094	*	-0.200	**	-0.020		-0.023	+	-0.010		0.030	
Annual	**-0.877**	*	**-1.270**	**	**-0.158**	*	**-0.429**	**	**-0.039**		**-0.059**	*	**-0.239**	**	**-0.020**	
Maximum flows																
J	-0.286		-1.057	*	-0.256	*	-1.038	**	-0.150	***	-0.035		-0.191	+	-0.179	
F	**-5.324**	*	**-1.200**	**	**-0.861**	+	**-4.333**	**	**-0.258**	***	**-0.530**	**	**-0.933**	*	**-1.211**	*
M	-0.931		-2.775	+	-0.427		-1.600	+	-0.202	**	-0.147		-0.366		-0.585	+
A	-0.286		-0.800		-0.193		-0.263		-0.161	**	-0.056		-0.322		-0.277	
M	-1.466	*	-2.374	*	-0.500	+	-0.394		-0.190	**	-0.054	**	-1.855	**	-0.172	
J	-1.380		-0.615		-3.000	*	-1.229	**	-0.219	**	-0.054	*	3.545		-0.270	
J	-2.093	*	-3.571	*	8.040	***	-0.709	**	-0.125		-0.085	**	-0.722	**	-0.767	**
A	**-0.107**		**-0.193**		**-0.096**		**-0.277**	+	**-0.140**	+	**-0.040**	*	**-0.053**		**-0.016**	
S	-0.167		-0.342		-0.007		-0.329	***	-0.157	*	-0.023	*	-0.063		0.150	
O	0.072		-0.042		0.000		-0.118		-0.164	*	-0.022	*	-0.005		0.150	
N	**-0.227**		**-0.562**	+	**-0.128**	*	**-0.330**	**	**-0.176**	**	**-0.022**		**-0.092**	*	**-0.139**	
D	**-0.527**		**-0.500**		**-0.180**	+	**-0.309**		**-0.142**	**	**-0.040**	*	**-0.042**		**-0.272**	+
Annual	**-6.670**	+	**-6.898**	*	**-1.126**		**-2.308**	*	**-0.193**	***	**-0.362**	*	**-2.529**	*	**-0.670**	

Trends were calcualted both for mean discharge and for maximum discharge flows. Thus, the general trend of the region is that of decreasing for mean flows as well as for maximum ones. For all the rivers considered, from November til May, but also in August, all the stations datasets have decreasing trends. For decreasing during wintertime, the main causes seem to be the same like those for mean discharge. For maximum discharge during summer, only two data sets have positive slopes. In this situation one can consider that to the decreasing precipitation increasing evporation as a consequence of increasing temperature is added. The extremly high slope of July on Teleorman river is mainly due to the catastrophic floods of summer 2005. Then a historical discharge flow of 75.2 m^3/s was recorded and it was generated by a three time higher precipitation amount compared to the mean multi-annual value of July.

Considering the slopes, for the most important rivers of the region, the flow decreased by 0...22% for the whole period (between 0 and 9%/decade). This rates are much higher compared to those estimated by models for Eastern Europe (0-23% untill 2020) (IPCC, 2007).

At Alexandria, the occurence probability of the mean multi-annual discharge flow (7.65 m^3/s) is higher than 50 % of he total cases, while the discharge flow of 10.8 m^3/s has a probability of 20 % (figure 6). The 1% occurence probability flow has a value of 28.8 m^3/s, while the flow of 50.2 m^3/s has a probability of 0.1%.

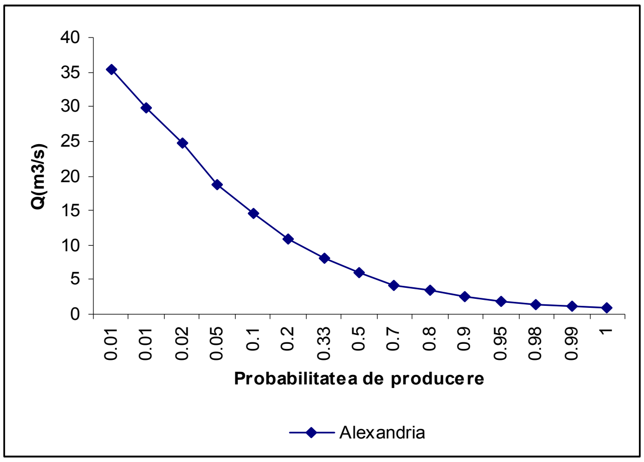

Figure 6. Occurence probability of the mean muti-annual discharge flow, Alexandria station

The occurence probability for the high water season is very different depending on the location of the station and of the river inside the basin (table 5).

Table 5. Occurance probabilty of the flow during high-water season

T	q	Pârâul Câinelui	Vedea	Tătărăştii de Sus Telerorman	Teleorman Teleorman	Călmăţui	Crovu Glavacioc	Vadu Lat Neajlov
10000	0.0001	26.9	267	21.8	72.7	8.23	19.4	39.3
2000	0.0005	15.7	154	13.2	44.7	6.67	10.9	26.1
1000	0.001	12.2	119	10.6	36.1	6.05	8.39	21.8
200	0.005	6.44	62.0	6.14	21.4	4.74	4.52	14.2
100	0.01	4.72	45.3	4.80	16.9	4.22	3.42	11.7
50	0.02	3.37	32.3	3.71	13.3	3.72	2.56	9.61
20	0.05	2.03	19.7	2.59	9.4	3.1	1.71	7.33
10	0.1	1.30	12.9	1.92	7.09	2.65	1.23	5.91
5	0.2	0.75	7.94	1.38	5.19	2.21	0.85	4.68
3	0.3	0.46	5.30	1.05	4.01	1.88	0.63	3.90
2	0.5	0.27	3.70	0.79	3.11	1.61	0.47	3.27
1.428	0.7	0.14	2.64	0.59	2.38	1.35	0.34	2.75
1.25	0.8	0.09	2.27	0.51	2.07	1.22	0.29	2.52
1.111	0.9	0.05	1.96	0.42	1.73	1.08	0.24	2.28
1.052	0.95	0.03	1.80	0.36	1.53	0.98	0.21	2.14
1.020	0.98	0.02	1.70	0.31	1.35	0.89	0.18	2.01
1.010	0.99	0.01	1.65	0.29	1.26	0.84	0.17	1.95
1.005	0.995	0.01	1.62	0.27	1.19	0.80	0.16	1.90
1.001	0.999	0.00	1.59	0.24	1.07	0.74	0.14	1.83
1.000	0.9995	0.00	1.58	0.23	1.04	0.72	0.13	1.81
1.000	0.9999	0.00	1.56	0.21	0.972	0.68	0.13	1.77

Correlation between precipitation and discharge flows

Correlation between precipitation and discharge flows considered sum of annual precipitations and the average values of annual discharge flows of rivers in the area. Correlation coefficient was calculated between the discharge flow of every hydrological station and the precipitation range recorded in the closest weather station for each location (table 6).

The analysis showed different results for rivers in the studied region. Thus, for the main river of the area, Vedea, the values of *r* coefficient indicate that there is a linear correlation between annual precipitation amounts and average annual discharge flows ($r > 0.50$) for the two couples of data series. For the second river in order of importance, Teleorman, the linear correlation was found only for one of the two analyzed couple of data series.

Little tributaries discharges do not correlate with precipitation ranges to any of the stations.

Table 6. Bravais-Pearson correlation coefficient

River	Hydrometric station	Weather station	Bravais-Pearson Coefficient
Vedea	Alexandria	Alexandria	**0.59**
	Văleni	Roşiorii de Vede	**0.67**
Teleorman	Tătărăştii de Sus	Piteşti	**0.53**
	Teleormanu	Alexandria	0.17
Cotmeana	Ciobani	Piteşti	**0.54**
Dimbovnic	Slobozia	Piteşti	0.36
Urlui	Furculeşti	Turnu - Măgurele	0.40
Pârâul Câinelui	Vârtoapele	Roşiorii de Vede	0.34

EXTREME HYDROLOGICAL PHENOMENA IN ROMANIAN PLAIN BETWEEN OLT AND ARGES RIVERS

Analysis of floods on rivers in Romanian Plain between Olt and Arges

For the floods analysis main parameters of the floods were calculated.

The main parameters of the flood calculated for this study were: the maximum flow of the flood (the peak of the flood), the increasing duration of the flood (accumulation time), the decreasing duration, the total duration, the total discharge, the water layer and the shape coefficient of the flood.

The total duration (hours) is defined as the total duration of the flood and is calculated as sum of increasing and decreasing durations.

The longest flood recorded in the area under study and for the period analyzed, was in 1977, from February 1st til february 23. It cumulated 520 h and was recorded on Cainelui Valley at Vartoapele station (table 7).

Table 7. Variation of total duration of the floods on the rivers in the Romanian Plain between Olt and Arges

No.	River	Location	Total duration minimum		Total duration average	Total duration maximum	
			hours	Year	hours	hours	Year
1	Călmă□ui	Crângu	43	2002	150	375	1970
2	Urlui	Furcule□ti	206	2005	241	518	1994
3	Teleorman	Teleormanu	40	2008	109	298	2006
4		Tătără□tii de Sus	15	1997	90	239	2004
5	Cotmeana	Ciobani	29	2004	82	273	1996
6	Pârâul Câinelui	Vârtoapele	48	1996	181	520	1977
7	Vedea	Buze□ti	24	1999	68	222	1988
8		Văleni	42	2005	95	274	1996
9		Alexandria	37	2008	118	463	2000
10	Dâmbovnic	Slobozia	36	2009	98	203	2003
11	Neajlov	Vadu Lat	46	2007	132	307	2006
12	Glavacioc	Crovu	54	1998	180	513	2003

Layer of the water discharged of the flood

The thickness of the water layer has diferent values according to the total volume of the flood and the surface of the hydrographic basin. The maximum values varied between 35.79 mm and 518 mm (table 10). The highest value was recorded in 1994 at Furculesti station, on Urlui River (518 mm). Other high values were recorded in 1972, on Vedea river, at Valeni and Alexandria stations (122, 76 mm and respectively, 118, 78 mm). At Alexandria, even if the surface of the basin is higher (3,246 km^2), the discharged layer was also high because during the October 1972 flood, the historical discharge flow was recorded (792m^3/s).

Table.8 Layer of the water discharged during flood events

No.	River	Hydrometric station	Maximum layer		Average layer	Minimum layer	
			Mm	year	Mm	Mm	year
1	Călmătui	Crângu	6.54	1984	2.63	0.55	2002
2	Urluiu	Furculeşti	518	1994	362	206	1994
3	Teleorman	Teleorman	23.44	2005	5.18	0.41	1995
4		Tătără□tii de Sus	50.96	2005	10.77	0.58	1994
5	Cotmeana	Ciobani	35.79	1995	10.48	0.25	1984
6	Pârâul Câinelui	Vârtoapele	91.78	1972	13.74	0.88	1970
7	Vedea	Buze□ti	29.58	2005	8.44	1.11	1988
8		Văleni	122.87	1972	13.55	1.06	1970
9		Alexandria	118.76	1972	11.29	0.67	1972
10	Dâmbovnic	Slobozia	42.57	2005	6.42	0.29	1990
11	Neajlov	Vadu Lat	55.17	2005	9.53	0.48	1995
12	Glavacioc	Crovu	28.27	1997	8.33	0.92	1996

The maximum discharge flow

The highest values of the maximum discharge flow were recorded at stations located on Vedea river.

Thus, at Alexandria, the highest flow of a flood event was of 935 m^3/s and was recorded on 11 October 1972 at 23.00 (figure.7); at Valeni station, the highest flow was recorded on July 3, 2005, 14.00 h (751m^3/s), while at Buzesti station the highest value was recorded on May 23, 1995, 17.00 h (345 m^3/s).

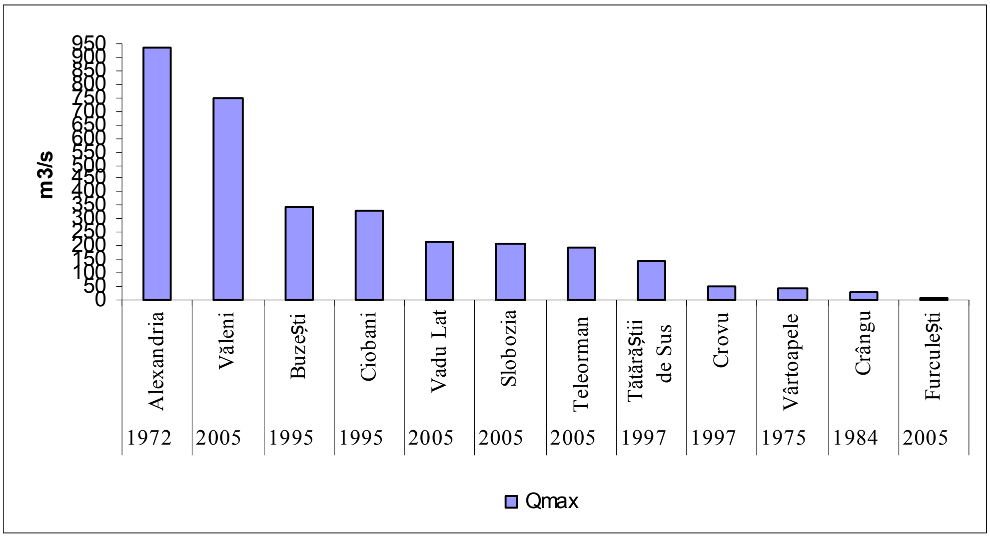

Figure 7. Variation of the maximum discharge flow of the floods recorded on rivers in Romanian Plain beween Olt and Arges rivers

Frequency of flood occurence

From the total amount of floods, the most frequent are those with a duration between 50 and 150 hours, representing 57.09%, while floods with a duration of 150-250 h represent only 20.17%. The lowest cases are floods with a longer duration, more than 350 h (2.20%) (table 11)

Table. 9.Flood frequency considering the total duration

No.	River	Station	Number of floods with duration of ...(h)				
			>350 h	250-350 h	150-250 h	50-150 h	< 50 h
1	Călmățui	Crângu	1	3	12	16	1
2	Urlui	Furculeşti	1	0	1	0	0
3	Teleorman	Teleormanu	0	1	2	19	2
4		Tătărăştii de Sus	0	0	2	20	5
5	Cotmeana	Ciobani	0	1	2	16	16
6	Pârâul Câinelui	Vârtoapele	3	4	10	17	1
7	Vedea	Buzeşti	0	0	1	13	14
8		Văleni	0	1	3	21	6
9		Alexandria	1	1	6	17	4
10	Dâmbovnic	Slobozia	0	0	6	19	3
11	Neajlov	Vadu Lat	0	1	8	16	1
12	Glavacioc	Crovu	1	0	11	9	0
13	**Total**		**7**	**12**	**64**	**183**	**53**

If seasonal occurence of the flood is considerd, one can see that the most floods are specific to winter (129) and spring (122) as a consequence of high amounts of liquid precipitation cumulated with the quick snow layer melting and a low evaporation (figure 8).

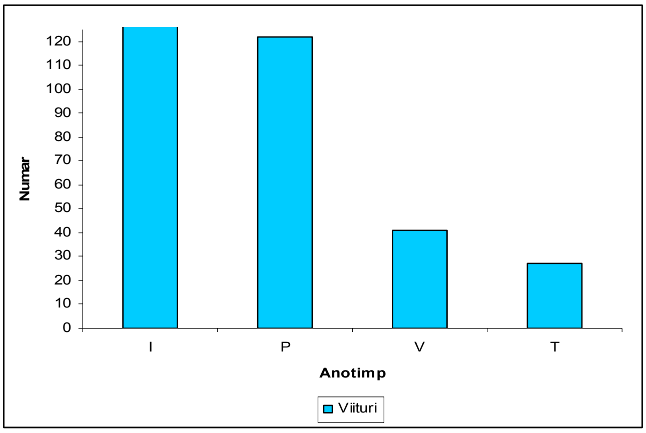

Figure. 8 . Seasonal frequency of theflood occurence

Summer flood of 2005

The year 2005 was charaterized by both extremely high amounts of precipitation and huge discharge flows on the rivers. For instance, at Alexandria weather station, 1061 mm of precipitation were recorded, reprezenting almost double value if compared to the mean multi-annual value (536.8 mm). Months from May till September recorded amounts 100-150 mm higher compared to the mean multi-annual values. Those volumes of waters generated huge highfloods on the rivers.

The synoptic situation which determined the heavy rains from 2-7 July 2005, was characterized, initially, at the 500 hPa isobaric surface level, by a western circulation.

At sea level, the most part of the continent was under the rule of low pressure centers. Only the Northwestern Scandinavia was an exception dominated by a high pressure center.

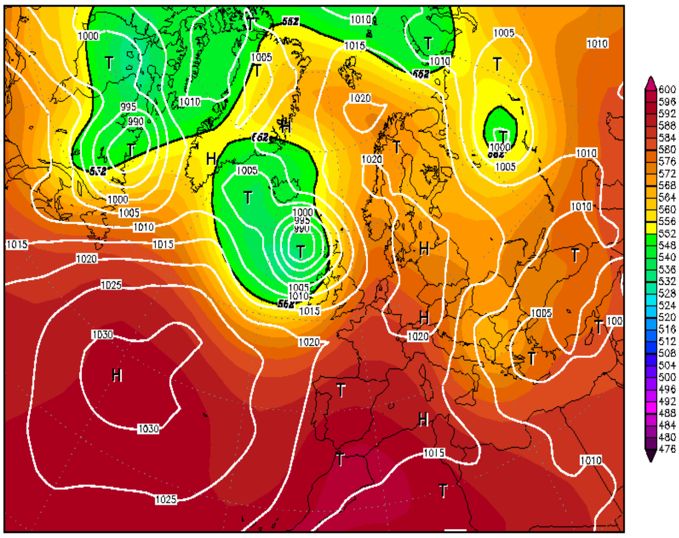

Figure.9 .Geopotential at 500 hPa isobaric surface level (5500 m) and sea level pressure on 03. 07. 2005, ora 00^{00} (after www.wetterzentrale.de)

From 2 to 4 July, over Romanian territory a mediterannean depression was acting, especially over the souther part of the country. It developed under the cold nucleus identified at 500 hPa, while the southewestern Europe was under the warm high pressure center,originated in Norther Africa and developed in the high altitude. (figure 9).

In those conditions, huge amounts of precipitaion were recorded in the Central romanian Plain: 197 mm at Buzesti, 218 m, at valeni and 143.4 mm, at Alexandria.

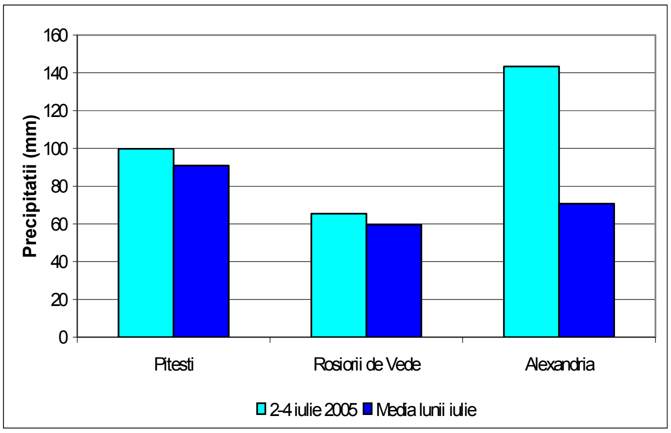

Figure.10.Precipitation amount fallen from 2 to 4 July 2005 and the mean multi-annual monthly amount of July

Using the floods graphics, the parameters have been calculated for each station where the flood occured in July 2005.

Table 10. Direct stream flow and flood parameters at stations where flood occured in July 2005

Parameters \ River and station		Vedea River			Glavacioc River	Teleorman River		Câinelui River
		Buzeşti	Văleni	Alexandria	Crovu	Teleor-manu	Tătărăştii de Sus	Vârtoapele
Direct stream flow parameters	QmaxV (m^3/s)	192.51	730.54	734.56	37.09	179.86	66.88	10.42
	WcV (mil.m^3)	4.49	22.09	38.26	1.09	5.97	0.59	1.24
	WdV (mil.m^3)	8.34	52.83	28.13	8.59	16.46	7.82	0.97
	WtV (mil.m^3)	12.83	74.92	66.40	9.68	22.43	8.41	2.21
	HsV (mm)	25.92	43.46	20.46	15.08	16.73	20.26	9.24
	GammaV	0.36	0.41	0.40	0.42	0.36	0.48	0.51
Flood parameters	Qmax (m^3/s)	208.00	751.00	834.00	39.60	196.00	75.30	12.00
	Wc (mil.m^3)	4.92	22.92	44.14	1.31	6.95	0.79	1.43
	Wd (mil.m^3)	12.86	60.57	45.10	11.38	24.50	10.59	1.50
	Wt (mil.m^3)	17.78	83.48	89.25	12.69	31.45	11.34	2.93
	Hs (mm)	35.92	48.43	27.49	19.77	23.45	27.33	12.27
	Gamma	0.47	0.45	0.48	0.52	0.46	0.58	0.59
	Tc (h)	14	18	30	39	27	7	49
	Td (h)	37	51	32	133	70	65	66
	Tt (h)	51	69	62	172	97	72	115

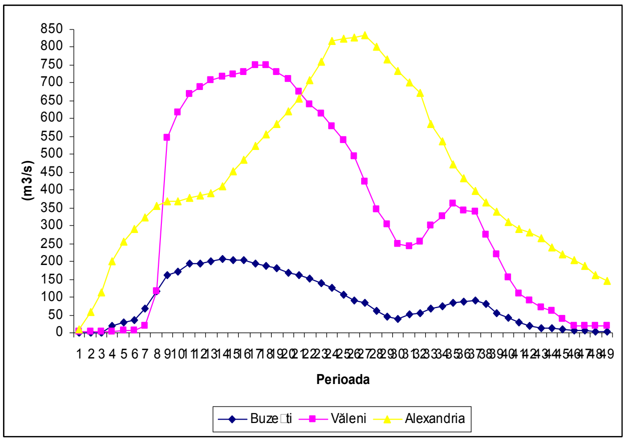

Figure.11 July 2005 flood graphs, Vedea river

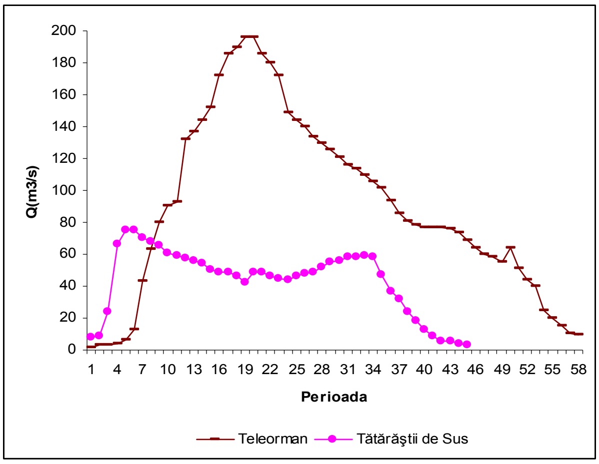

Figure.12 July 2005 flood graphs, Teleorman river

Using the information released by Administration and Home Ministry, one can notice that in Teleorman County, 33 settlements have been affected by flood, 4545 inhabitans have been evacuated and more than 5000 houses have been damaged and 40 houses have been isolated because of the bridges crash. 292 families became homeless, as their houses were completely destroyed. The total amount of damages increased up to 10.000.000 USD.

By special measures taken Emergency Situations Inspectorate, inhabitants and the cattle in the affected settlements have been evacuated. The inhabitants have been accomodated in schools, hospitals and cultural centers buildings.

The flood damaged eight 8 hydraulic engineering works and broke 21 dams. Over the little tributaries, 83 footbridges have been completely destroyed. Because of that 40 houses became isolated.

Table 11. Impact of July 2005 flood in RP
(after Buletinul informativ al Ministerului Administrației şi Internelor, July 2005)

No	County	Settlement feced	Victims	Evacuated inhabitants	Distryed houses	Damaged houses	Isolated houses	Household annexes	institutions	Broken dams	Bridges and footbridges	roads (km)	Water supply network (km)	Agricultureal terrain (ha)	cattle	hay
1	Argeş	10	0	0	0	78	0	95	0	2	13	19	0	1871	0	52
2	Giurgiu	7	0	137	1	47	0	65	1	0	4	30	0	0	138	47
3	Olt	9	1	0	0	9	0	31	0	0	0	30	0	1910	0	43
4	Teleorman	33	2	4545	291	4983	40	3746	31	19	66	418	1	831	10306	490
5	**Total**	**59**	**3**	**4682**	**292**	**5.114**	**40**	**3936**	**32**	**21**	**83**	**494**	**1**	**4612**	**10.442**	**632**

Atmospherical drought

We considerd necessary to study the atmospherical drought because it is the main cause of the hydrological drought.

Atmospherical drought ussualy is a consequence of the absence of precipitaiton, especially liquid precipitation, but also of the relative humidity less than 40 % and of higher air temperature. In Romania, the absence of precipitation is generated by the presence of the stable high pressure centers, covering a large part of European continent.

In the studied region, there have been identified many dry spells. Thus, in the 39 years, dry spells and drought wee recorded in 18 years at Pitesti, in the north of the region and in 25 years, at Alexandria, in the centre of the area.

Stream flow drought analysis

Southern and Eastern regions of Romania are considered more and more vulnerable to different kinds of drought: meteorological, hydrological or pedological. The implications become more important because they are considered as main agricultural areas of the country (Croitoru and Toma, 2010). That's why many authors studied the drought from meteorological (Bogdan and Niculescu, 1999, Stângă, 2009) or hydrological perspectives (Ştefan et al., 2004, Ghioca, 2008, Holobâcă, 2010, Sorocovschi, 2010).

Hydrological drought in terms of stream flow drought is defined when the flow decreases below a given values. It defines a threshold, *q0*, below which the river flow is considered as a drought (Yevjevich, 1967). This approach allows simultaneous characterisation of stream flow droughts in terms of duration (d_i), severity (or deficit volume, s_i) and time of occurrence (Hisdal et al., 2001).

Among other types of thresholds (a well-defined flow quantity, a percentage of the mean flow), we decided to use a percentile from the flow duration curve because expressing flows as exceedance values allows flow conditions in different rivers to be compared.

According to European Union Project ARIDE (Demuth and Stahl, 2001), the threshlod may vary from 70% to 90% exceedance probability. For this study, the 80% exceedence probability of seasonal flow was used for many reasons. In the case of a longer than one season drought event, the threshold changes according the specific flow. High flow season was considered from November till March, while low flow season was from April till October.

Data

For hydrological drought, daily data of the discharge flows recorded in seven hydrometric stations were employed (fig.2). Five of the hydrological data sets covered 30 years, from 1980 until 2009. Only two hydrological data series are available for a period of 22 years long (those recorded on Glavacioc and Neajlov).

Then, five specific parameters of the hydrological drought (HD) have been analysed: mean multiannual number of the hydrological drought events (HDE), mean multiannual duration of the HDEs, maximum duration of HDEs both in their average and absolute values, mean annual cumulated duration of HDEs, average daily discharge during HDEs and the mean discharge deficit volume (Table 12).

Finally, trends in the specific parameters of HD were identified.

The *mean annual number of HDEs* varies, generally, between three and nine, while the maximum number of events was between 10, in the eastern part of the region, and 25, in central area. Otherwise, the analysis revealed for Teleorman river the highest values both for average and for maximum number of HDEs, for the two hydrometric stations considered. It worth mention that there are two rivers that experienced years without any HDE (Călmățui and Neajlov) at the end of ‘80s and at the beginning of the ‘90s.

The longest HDEs as average values were recorded on the lowest rivers in terms of discharge flow, Câinelui and Galvacioc, while the lowest values were specific to southern stations: Teleormanu and Crîngu on Teleorman and Călmățui rivers.

Cumulated duration of HDEs analysis show that dry periods are more longer in Vedea Hydrographic basin than in the others, with more than 140 days/year as average and more than 300 days/year as maximum values.

If the *absolute maximum duration of a single HDE* is considered, the variation in the area is very large, from less than 200 days, on the most important river, Vedea, up to almost 500 days, on the little Câinelui River.

Actually, considering both mean and absolute maximum values of HDEs, no rule seems to be identified in the area between multi-annual discharge flows values and the length of HDEs. Thus, we consider that rather meteorological factors, such as temperature and the intensity of the evaporation, may play the main role in the occurrence of the HDE than hydrological parameters values of the analyzed rivers.

As expected, the mean multi-annual daily discharge during HDEs, has the highest values on Vedea River and the lowest on Câinelui River.

Table 12. *The hydrological drought parameters in Central Romanian Plain (1980-2009)*

Hydrographic basin		**Vedea**				**Cal-ma-tui**	**Argeş**	
Parameter \ **River**		Vedea	Teleorman (Tatarasti HS[1])	Teleorman (Teleormanu HS)	Valea Câinelui	Călmățui	Neajlov[2]	Glavacioc[2]
Annual number of HDE [5]	m[6]	1	3	3	1	0	0	1
	A[7]	6.8	8.14	11.1	4.3	4.2	3.32	5.82
	M[8]	15	25	18	12	12	12	10
Annual mean of HDEs duration (days)	m	3.0	4	1.7	2.5	0	0	3.6
	A	25.8	25.9	15.5	47.7	14.9	18.4	29.6
	M	108	106	40.7	149	53.7	122.5	190
Average cumulated HDEs duration	A	141.6	161.6	158.2	184.6	87.5	77.3	118.5
	M	324	365	300	567	322	252	246
Absolute maximum duration of one HDE (days)	M	198	306	164	492	278	244	190
Multiannual average daily discharge during HDE (m^3/s)	m	1.44	0.373	1.21	0.017	0	0	0.114
	A	1.85	0.5	1.43	0.048	0.6	1.4	0.206
	M	2.31	0.705	1.85	0.093	1.78	2.47	0.391
Multiannual mean streamflow deficit (mil. m^3)	m	1.85	0.9	1.6	0.2	0	0	1.1
	A	67.1	11.4	25.1	6.61	5.5	12.7	5.97
	M	175.5	29.5	51.3	39.6	18.2	50.2	13.4

Note: [1] – Hydrographic Station; [2] – Data available for 1988-2009; [3] –Mean multiannual discharge flow [4] – Exceedance probability threshold; [5] – Hydrological drought event; [6] – minimum value; [7] – mean value; [8] – maximum value; [9] - Hydrological drought.

The highest values of the multi-annual stream flow deficit volume were found on the main rivers (Vedea and Neajlov), but the lowest value was not on the less important river in terms of mean multi-annual discharge flow (Câinelui river).

A stream flow deficit volume analysis shows the lowest value specific to Galvacioc and not to Câinelui River. Mean multi-annual deficit value recorded on Câinelui River ranges this river as the fifth in decreasing order, before Călmățui and Glavacioc while, if maximum annual values of the deficit volume are considered, the same river can be placed also before upper Teleorman river (Tătărăştii de Sus hydrographic station).

Trends of hydrological drought parameters

For the same parameters, trends were identified and mean slopes were calculated for the 30 years period considered (table 15).

Generally, there is an increasing trend of hydrological drought phenomenon in the area characterized by fewer events, but which are longer. The most important duration of drought was specific to central area, on Câinelui River, both in terms of mean multi-annual value and absolute maximum values of the 1980-2009 period. The most important intensity (given by the stream flow deficit volume) was specific to the main rivers of the area (Vedea and Neajlov).

Table 13. The hydrological drought parameters trend in Central Romanian Plain (average slope/decade)

Hydrographic basin		**Vedea**				**Cal-matui**	**Argeş**	
Parameter \ **River**		Vedea	Teleorman (Tatarasti HS)	Teleorman (Teleormanu HS)	Valea Câinelui	Călmățui	Neajlov[2]	Glavacioc[2]
Mean annual number of HDE	Q	-0.250	-0.085	-0.231	0.000	0.235	0.000	-0.125
	α	*		*		**		
Mean annual HDE length (days)	Q	0.914	0.722	0.528	1.363	0.731	1.229	0.297
	α	**	*	**	+	**	+	
Mean annual number of HD days	Q	3.235	4.165	2.091	4.933	5.100	4.000	-3.235
	α				+	***	*	
Absolute maximum HDE length	Q	1.905	1.477	1.533	2.636	2.813	2.500	-1.500
	α	+	+	+		***	+	
Mean daily discharge during HDE (m^3/s)	Q	-0.002	0.000	0.004	0.000	0.000	0.000	-0.004
	α							+
Mean annual stream-flow deficit (mil. m^3)	Q	1.484	0.298	0.512	0.110	0.307	0.696	-0.161
	α		+			***	*	

Note: [1] – Statistically significance: α= 0.1; * - α=0.05; ** - α=0.01; *** - α=0.001.

Dryness phenomena were recorded only on one river (Câinelui river).

CONCLUSIONS

Analysing the extreme hydrological phenomena in Romanian Plain between Olt and Arges rivers, we have anlysed floods and droughts recorded between 1965 and 2005.

For the period considered, decreasing trends both of the mean and maximum discharge flows were computed together with increasing trends of the air temperature and decreasing slopes of the precipitation amounts. The Bravais-Pearson revealed direct connection between decreasing precipitation and decreasing stream flows.

In the 41 years of the interval, 319 floods occurred. The most part of them were recorded during winter and spring: 40.43 % and respectively, 38.24%. Lower values characterized summer (12.85 %) and autumn (8.46 %).

For the floods occurred in the warm semester, the heavy precipitations were the triggering factor, while for the floods of the cold semester, precipitations together with incresing temperature and melting snow became the triggering factors.

Analysing the statistical data of the 12 hydrological stations considered in the region and also the data provided by local authorities, one may conclude that anthropogenic factor was an important influencing and control element of floods occurring and intensity. The human activities in the area with a negative impact on hydrological network were: the developping of irrigation systems, the construction of the storage lakes and other hydrotechnical works; chemical pollution that affects the vegetation in the minor rivers beds; the defforestation represent the most important damage, especially when it is done along the slopes. Although it affects little surfaces, the superficial cover of the soil is removed by the pluvial water.

Analysing the hydrological drought parameters there are few main conclusions we reached at.

Thus, there is no direct or reverse correlation between mean multi-annual discharge flows and the parameters of the hydrological drought events in the area.

Generally, there is an increasing trend of hydrological drought phenomenon in the area characterized by fewer events, but which are longer. The most important duration of drought was specific to central area, on Câinelui River, both in terms of mean multi-annual value and absolute maximum values of the 1980-2009 period. The most important intensity (given by the stream flow deficit volume) was specific to the main rivers of the area (Vedea and Neajlov). Dryness phenomena were recorded only on one river (Câinelui river).

The most important impacts as a consequence of the human activities, in the area are erosions of the banks, which influence the stability of the buildings and roads and destroy the agricultural surfaces.

Floods and drought have their main effects on agricultural as well as on the other branches of the economy. Negative impacts on the environment may lead to catastrophic consequences on human lifes quality in the considered area.

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