# OBSERVATIONS ON THE SPATIAL VARIABILITY OF THE PRUT RIVER DISCHARGES

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**Key words:** uneven spatial variation, sunspots, torrential rainfall, spatial analyses, monthly analyses.

**ABSTRACT:**

Liquid and solid discharges of the Prut River were analysed based on measurements performed in 7 points from the Romanian national network of water monitoring during a period of 30 years. The analyses were performed on flows for the period after the construction of the Stânca-Costeşti dam and show the influence of the dam for the entire analysed time. The analysis from upstream to downstream of the spatial variability of the Prut River annual discharges showed their steady increase downstream and then a decrease in the sector next to Oancea station. A statistical minority of the annual discharges showed a continuous increase of them until the flowing of Prut into Danube. Knowing that the lower basin of the river is characterized by a low amount of rainfall and a higher evapo(transpi)ration than the remaining basin, the decreasing flows to the river mouth is explicable; but the increasing flows to the river mouth cannot be justified, under these conditions of water balance, than by certain climatological parameters of thermo-dynamical nature which generate, with increased frequency, more intense and rich rainfall, with a torrential character. The analyses on couples of three months showed that the Oancea flows are higher than the upstream stations (opposite than usual) in years when the flows of the upstream hydrometrical stations are lower than the multiannual average and that supports the mentioned pluviometrical character. A plausible cause for "Oancea phenomenon" is the increase and the decrease of the sunspots number, whose cycles are relatively well fold on the increase and decrease of annual average flow at Oancea hydrometrical station. The strongest increased discharges of the Prut River over the discharges at the upstream stations occur from May to July (MJJ), the months with the highest amount of rainfall. Seasonal analysis of MJJ and other couples of 3 months showed that there are also growing flows at Prisăcani station relative to the adjacent stations, but only in MJJ. This increase at Prisăcani is due to the local influx of water, not to the decrease of the flow at the upstream and downstream stations. Prisăcani influx of water is due to the large volume of rainfall in early summer on Iaşi Coast caused by the numerous orographic convections, volume found then in the permanent flow. The Stânca section has a contrasting variability too, but here is an explicit anthropogenic cause, namely the upstream dam. We conclude the analysis of the Prut river runoff spatial variability by showing that the river doesn't have a linear model, but one with local deviations whose manifestations can be attributed to the climate and anthropic specificity of the considered sector.

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## 1. Introduction

Prut is a river in the SE Europe and the points used to measure its discharge characteristics analysed in this article are placed in the middle and lower sections, where the river is the border between Romania and Moldavia (figure 1). Its headwaters are in the Wooded Carpathians, in Ukraine, and it flows into the Danube. Prut River Basin is located between the Carpathian Mountains (NV), the Podolian Plateau (NE and E) and the Moldavian Plateau (SV and V). Prut River Basin is the eastern extremity of the Danube Basin, being extended from 24°06’20” to 28°37’21” long. E and between 48°53’05” and 45°26’37” long. N. The total area of the Prut River Basin is 28463 km$^2$ and the river has a total length of 946 km.

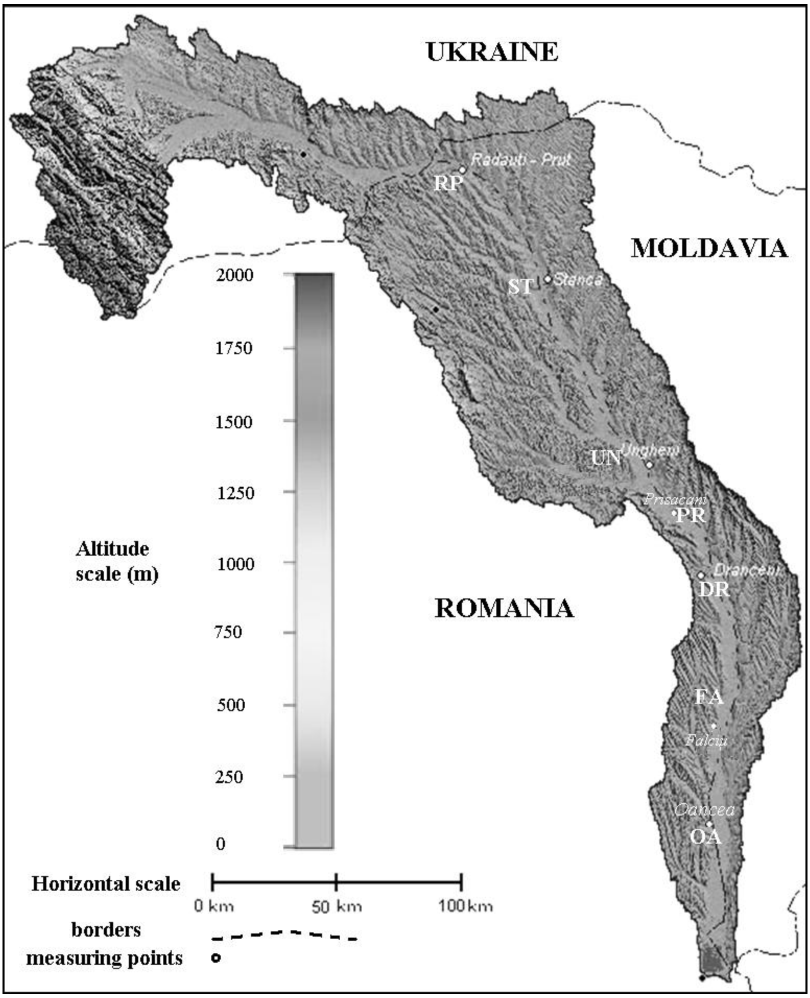


**Fig. 1.** DEM of the Prut Basin with the location of the discharge analysis points.

The Prut River has the hydrological regime of the Eastern Carpathian hills, the Moldavian one, with a period of low waters during the spring and with a high flow on summer (Ujvari, 1972), but mentioning that the melting in the first part of the spring is contributing to the annual flow at least equally with the summer rainfall. Spring flow is of average 45-50% of annual flow (Rădoane et al., 2006). The large volumes of spring water are due to the gradual melting of snow, depending on altitude and latitude. Average discharges in autumn represents between 10% and 15% of the average annual flow and in winter between 10% and 15% because a large amount of precipitation falls on the basin surface as snow and remains blocked in this way until the spring melting (Vartolomei, 2008). In summer, the volume of water transported by Prut and its tributaries is between 20% and 30% of the annual volume (Vartolomei, 2008). Along the Prut River, the maximum flow is achieved in the May-June months in Ukraine (in Cernăuți) and in April-May at the hydrometrical stations in Romania, reaching values between 140 and 180 $m^3/s$ between Rădăuți-Prut and the flow into the Danube (Rădoane Maria et al, 2007).

Along the Prut River, the average annual flows (figure 2) increase from Cernăuți (73.6 $m^3/s$) to Fălciu (103.4 $m^3/s$) and then decrease to the river mouth (85.3 $m^3/s$ at Oancea).

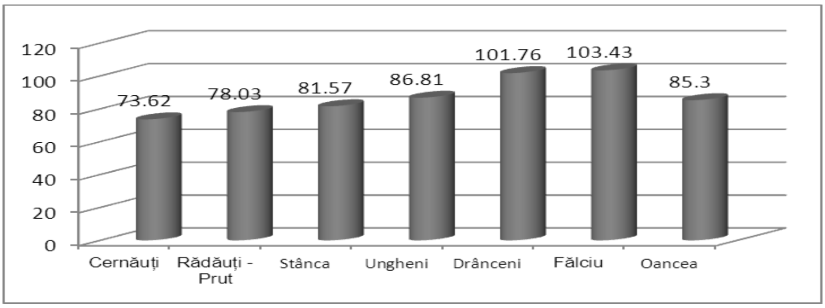


**Fig. 2.** Spatial evolution of the annual average liquid flow ($m^3/s$) between 1975 and 2006 from upstream to downstream.

## 2. Runoff controlling factors

In 1978, the dam from Stânca-Costeşti was given into exploitation having a maximum capacity of 1290 million $m^3$ of water and a surface of 77 $km^2$ and intended for a complex use: flood mitigation, electricity, water supply (for the cities of Iaşi and Bălți), irrigation and fishing. This lake affects the water volumes released downstream by retaining a variable percentage of the annual flow and is a minor cause for the later decreased flow at Oancea.

The geology of the basin has a high influence on the liquid and solid discharge of the Prut River. The subsidence area, the homocline structure of the deposits in the south basin and their petrography partially explains the lower discharges of the Prut in the lower basin. Rocks in the Prut River bed of the studied area (middle and lower basin) are, generally, friable, characteristic to the

Moldavian Platform (clay, marl, sand, thin oolithic limestone strata, calcareous sandstone, conglomerate, gravel, andesitic cinerea) with the mention that the sedimentary facies of the middle basin is a clay-marl one, while the lower basin is predominantly a sandy facies (Rădoane Maria et al, 2007). Facies changes affect the volumes of liquid and solid discharges and the composition of the solid one.

The main factor (and whose implications will be analysed in this article) that lowers the discharges at Oancea is the climate.

In terms of heat, the northern part of the basin is in a gap of 2.2°C against the southern part (8.4°C average annual temperature at Dorohoi, compared to 10.6°C at Galați). Monthly average temperatures are down to -3.6°C in January at Dorohoi and -2°C at Galați; they go up to 19.5°C at Dorohoi and 22.4°C at Galați in July (figure 3). We note, again, for the representative months of the year, the superior thermal potential of the lower basin than of the upper basin.

The annual average thermal amplitudes in the Prut basin are large (over 24-25°C) and correspond to a typical continental temperate climate; the annual absolute thermal amplitude, of over 75°C, argues the thermal continentalism (Vartolomei, 2008). Due to the interaction between the advection processes and the local circulation ones, generated by the heat balance of the active surface, the air temperature can reach 35-40°C in summer (Vartolomei, 2008). Large thermal jumps from one day to another (sometimes of over 15°C) are characteristics of the transitional seasons and explain the rapid melting of snow and ice in spring, which favours the occurrence of floods (Vartolomei, 2008).

The thermal aspect is important in terms of pluviometry characteristics, of evapo(transpi)ration intensity, of rainfall types, of river frost phenomena etc.

Annual average rainfall varies from 566.8 mm (Darabani) to 489.7 mm Galați). The most dry months (February - Darabani, January - Galați) have 22.9 mm and 27.8 mm rainfall, respectively. The rainiest month (July) has 90.6 mm and 67.1 mm at Darabani and Galați, respectively. Heat and rainfall waves (figure 3) impose a cyclic evolution of the annual river flow in the research area. Compared to the average trend, in the most dry months, the rainfall may be missing (e.g. from 408 analysed months in the 1962-1997 time interval in Jijia Plain, there are 31 months without precipitation (Mihăilă, 2006)) and in the most rainy one, the precipitation can exceed 3-4 times the monthly averages (e.g. 426.1 mm in May 1970 at Strunga).

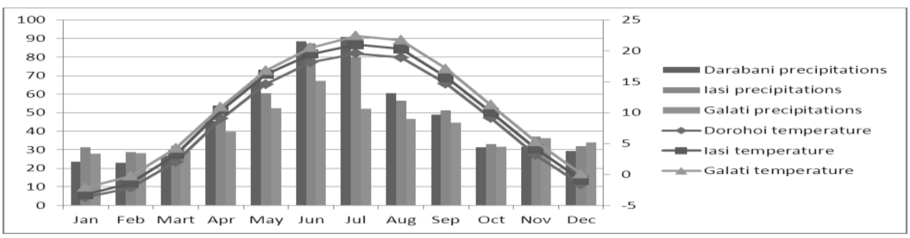


**Fig. 3.** Evolution of rainfall (mm) and of the annual air temperature (°C) at various weather stations in the median and in the N and S extremities of the studied area.

Both rainfall excesses generate the baseflow and the high waters (including floods) on the river (e.g. the over 4500 $m^3/s$ flow at Rădăuți-Prut on 28 July 2008 (Mihăilă et al., 2009).

## 3. Methodology and used data

The performed graphic analyses are mostly spatial, not temporal, meaning that it can be remarked the evolution of discharges of years and of couples of years from upstream to downstream at the studied stations. There were used data from the stations Rădăuți-Prut (RP), Stânca (ST), Ungheni (UN), Drânceni (DR) and Oancea (OA) for liquid (1976-2005) and solid (1986-2005) flow analyses. For some liquid discharge analyses, data were supplemented with Cernăuți and Fălciu (FA) stations (both with the 1975-2006 time interval) and with Prisăcani (PR) station (1981-2005). Meteorological data were taken from Darabani, Iaşi, Galați and Dorohoi stations for the 1961-2006 period (air temperature) and for 1960-2010 (precipitation). The annual number of sunspots for the period 1976-2005 was analysed. Analyses of the spatial evolution of the discharge for each month separately were performed and, for an optimal synthesis, the months were divided into 4 groups: FMA (February, March, April), MJJ (May, June, July), ASO (August, September, October) and NDJ (November, December, January). The values for each of these four groups are the average of the three months included by each group. The groups were chosen especially for putting together the rainiest months and, then, the months of frost and thaw were chosen also. Because there were found correlations between the solar cycles and the years with average monthly flows at Oancea higher than of the upstream stations, spatial analyses were conducted on solar cycles; 3 cycles were used: 1976-1985, 1986-1995 and 1996-2005.

## 4. Results and discussions

The analyses of the liquid and solid discharges from upstream to downstream show an increase of the liquid discharge until Drânceni station (figure 4) and then a decrease, sometimes very pronounced, until the river mouth, as seen at Oancea station. The solid discharge has behaviour similar to the liquid one. It’s worth noticing that, in some years, the discharges at Oancea station are no longer smaller than the upstream stations, but equal to or slightly above.

A Prut basin characteristic is the great rainfall variability because sometimes the annual amounts of precipitation and the monthly values significantly exceed the annual average (1021 mm at Hudeşti in 1932 of which 311 mm in June). In other years, the annual and monthly mean values are lower than the multiannual average (211 mm/year in 1907 at Săveni or 4 mm in June 1945 at Iaşi) (Vartolomei, 2008). In order to see in which months the increasing of the discharge occurs at Oancea over the values of the upstream stations, we conducted monthly flow analyses, summarized in figure 5.

During the warm period of the year, the rains often have a torrential character and there are cases when the fallen amount in 24 hours reach or exceeds the average of that month (136.7 mm in 25.07.1970 at Iaşi), which increases the surface runoff. Torrential rains generate significant amounts of water (e.g. the rain from 17 to 19.06.1985 of 193.8 mm at Iaşi and 147.8 mm at Răuseni (Mihăilă, 2006)) and cause increased soil erosion and increased solid discharge of the Prut River (Vartolomei, 2008). The lower basin of the river shows a more pronounced continentalism than the rest of the basin and thus the increase of flow at Oancea can be attributed to the intense thermal convection in summer (figure 5, b1-3) and to the retrograde cyclones from the Black Sea. Flow increases over those of the upstream stations during spring at Oancea (figure 5, a1-3) are caused by the delayed snow melting, from south to north, of the Prut River Basin.

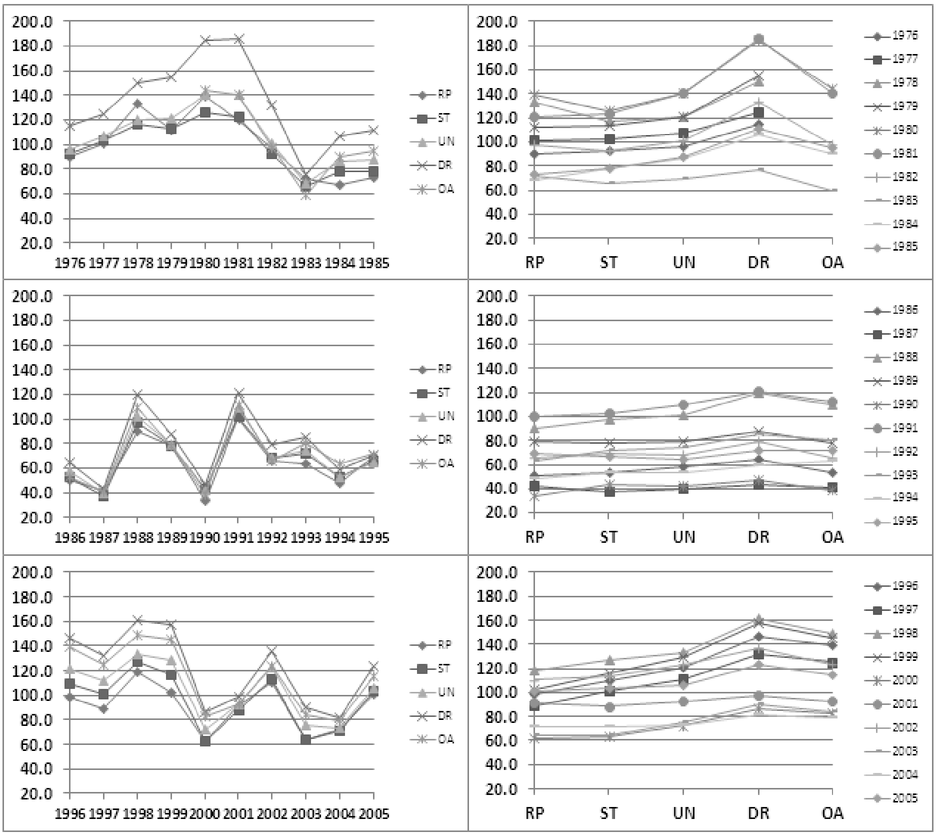


**Fig. 4.** Analyses per 10 years of annual liquid discharge ($m^3/s$) of the Prut river from upstream to downstream.

Another anomaly in river flow increase simultaneously with increasing river basin area is found at Stânca because the Stânca-Costeşti Lake is of major importance by retaining volumes of water. Downstream of the dam, at Stânca station, the long-term trends are the same as the upstream stations, but here there is a certain regulation of flows by the accumulation behind the dam because it ensures downstream a minimum flow of 35 $m^3/s$ . The flows analysed in this article refer almost exclusively to the period after the construction of the dam.

After 1978, after the commissioning of Stânca-Costeşti Dam, at Ungheni, Drânceni and Fălciu, the discharge trends of the upper basin are preserved, but the variability of the discharges becomes more and more high downstream (Rădoane Maria et al, 2007).

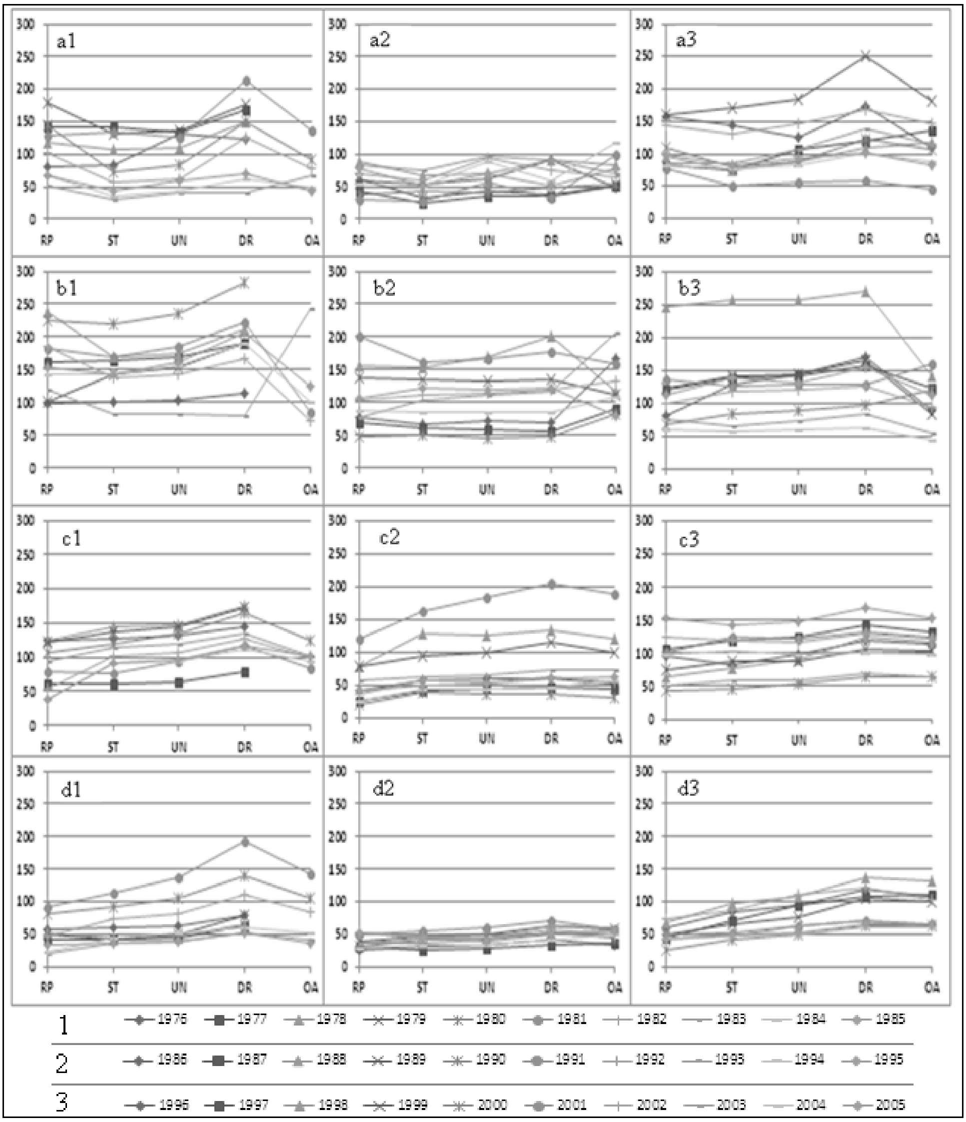


**Fig. 5.** Spatial evolution of the liquid discharge ($m^3/s$) - 1, 2, 3 – the decades 1976-1985, 1986-1995 and 1996-2005, respectively; a, b, c, d – the average discharge of FMA, MJJ, ASO and NDJ, respectively.

The solid discharge behaves almost similar to the liquid one and the Stânca-Costeşti Dam creates a discontinuity for this, also. The coarse material in the bed of the Prut River, at Stânca-Costeşti Lake, is generated from the crystalline area of the basin (1.05% of the basin), in the flysch area (12.72%) and in the Moldavian Platform sediments (86.22%)(Rădoane Maria et al, 2007), which determines different solid discharge characteristics upstream and downstream the lake. The strong growth, at Oancea hydrometric station, of the solid discharge of the Prut River at the same time with the liquid discharge (and over the values of the upstream stations at the same time) is due exclusively to the local alluvial input generated by heavy rainfall in the lower basin. The fact that Prut River at Oancea station had more years with higher (compared to the upstream stations) solid discharge than years with higher liquid discharge strengthens the idea of the increased discharge of the Prut River through torrents (figure 6).

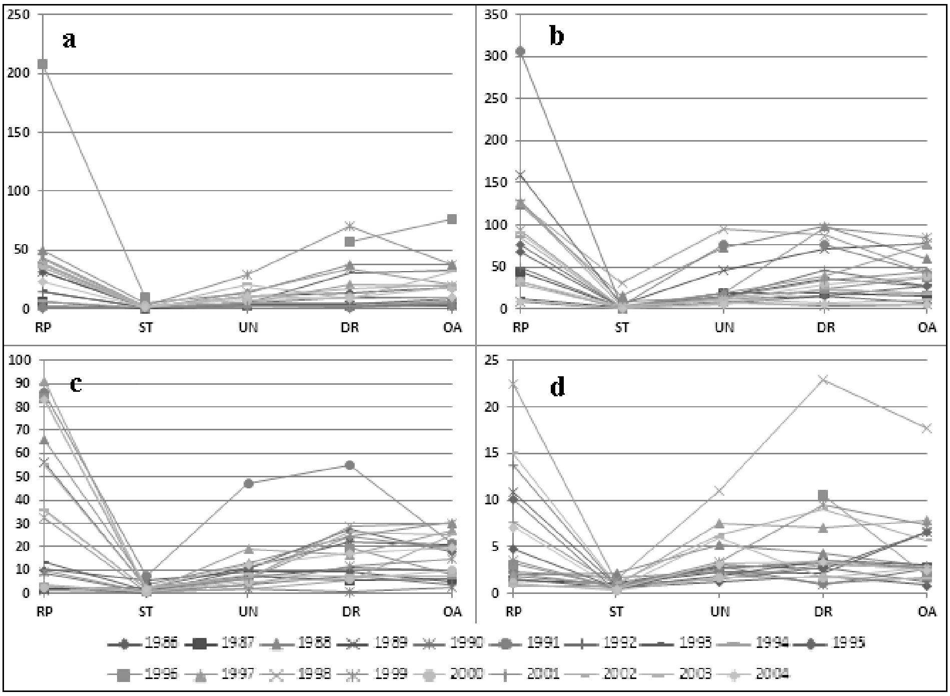


**Fig. 6.** The evolution per groups of months (a-FMA, b-MJJ, c-ASO, d-NDJ) of the solid discharge (kg/s), with different vertical scales in order to emphasize the fluctuations.

Only for liquid discharge we have made a new spatial analysis, with more stations (figure 7) for the time interval available for analysis. Excepting Oancea station, there isn’t any other upstream to downstream clear decrease. In MJJ, the decrease at Drânceni is relative to neighbours and is due to the superficially increased flow at Prisăcani because of Jijia discharge during the summer storms. Convective rains (of thermal and orographic nature), occured because of the air advection from NW to SE (the NW winds have a frequency of 22.3-31.1% in the Moldavia Plain) when it escalates the exposed NW edge of the Iaşi Coast, generate richer precipitation (790.3 mm at Bârnova, 665.4 mm at Mădârjac

(Mihăilă, 2006)). From the Iaşi Coast hills, the precipitation supplies Bahlui, Jijia and, then, the Prut River, causing local increases in Prisăcani flow. The pluviometrical role played by the artificial surfaces in Iaşi city and by the artificialized runoff of the Bahlui River in the same area is not negligible in explaining the discharge increases during summer at Prisăcani station.

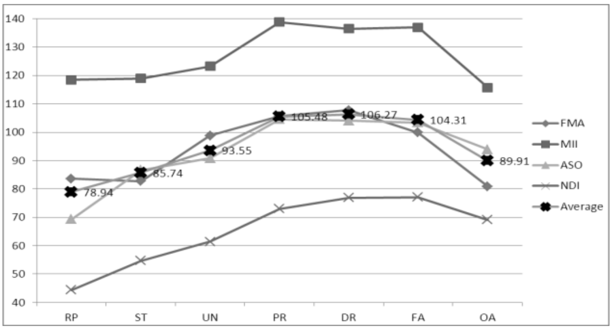


**Fig. 7.** Evolution during 1981-2005 of the Prut liquid flow ($m^3/s$)

A breakdown of MJJ (figure 8) in the period 1986-2005 shows that the growth over the trend of the Prisăcani discharges occurs in years with high flow rates, while the relative flow increases at Oancea occur in years with low flows. The temporal analysis of the annual average discharges (figure 9) shows that Oancea has a weak correlation with the average of the other stations (especially because of the MJJ group), while Prisăcani shows a good correlation.

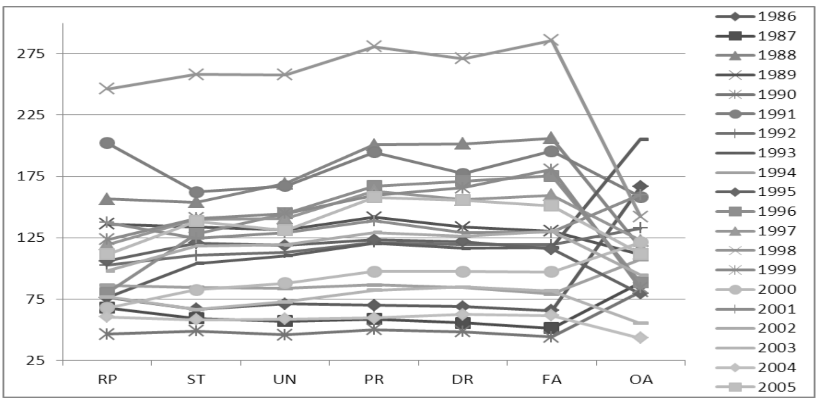


**Fig. 8.** The spatial distribution of MJJ flow ($m^3/s$) at Prut stations during 1986-2005.

Oancea has a controlling factor with an influence far greater than at the upstream stations. The annual cycle of weather and hydrography, with the highs and lows of their characteristic parameters (temperature, precipitation, flow), of the Prut Basin is governed by the global radiation regime of the latitude. We have identified strong correlations between the past three complete solar cycles and the Prut River flow regime (figure 10). In the years of maximum solar activity (warm years), when the Wolf Number is large, at Prut latitudes the active surface receives more energy and heat. Thermo-convective processes and evapo(transpi)ration are greatly amplified. During the cold years (the calm Sun), when the number of sunspots on the photosphere is minimal, the phenomenology is opposite.

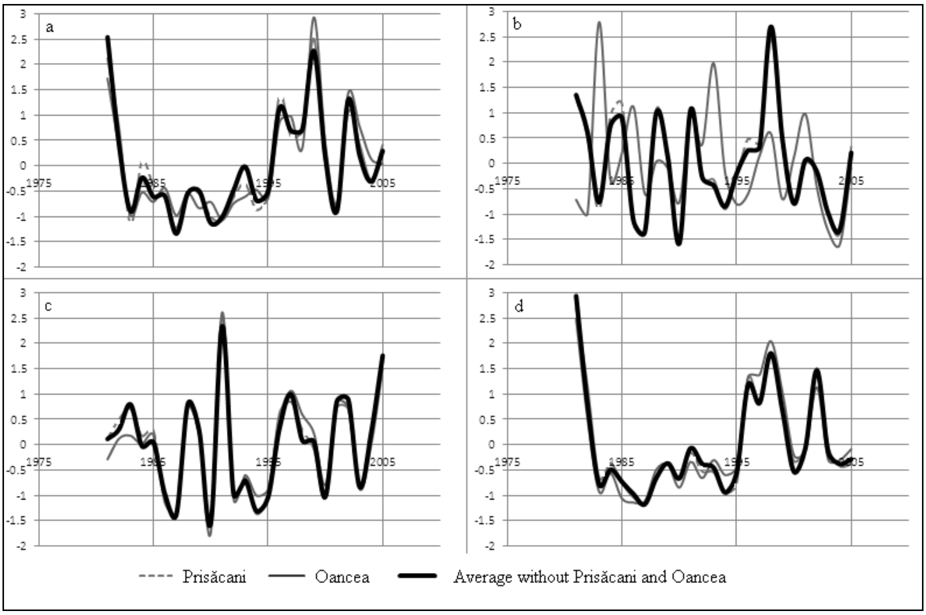


**Fig. 9.** The normalised evolution of annual mean liquid discharge at Prisăcani, Oancea and the average of the all other stations during 1981-2005; a, b, c, d - FMA, MJJ, ASO and NDJ, respectively.

The large number of sunspots is associated with enhanced atmospheric activity and strong cyclone activity and the atmosphere responds to the intense solar activity in two stages: it initially increase the number of storms and the temperature, but, beyond a certain number of sunspots, the latter decrease the solar constant value and the effect on cyclone activity and temperature is inversed (Chappell, 1971). The mentioned influence of sunspots number on climate is also supported by the latest studies (Perry, 2007, Chen et al, 2006, Lassen and Friis-Christensen, 1995). The indirect effect of sunspots on water resources was revealed by the analysis of river flow fluctuations (Hajian and Movahed, 2010, Ananthaswamy, 2008), of lake levels (Shermatov et al, 2004) and of paleodischarges through sedimentological studies (Xiao et al, 2006).

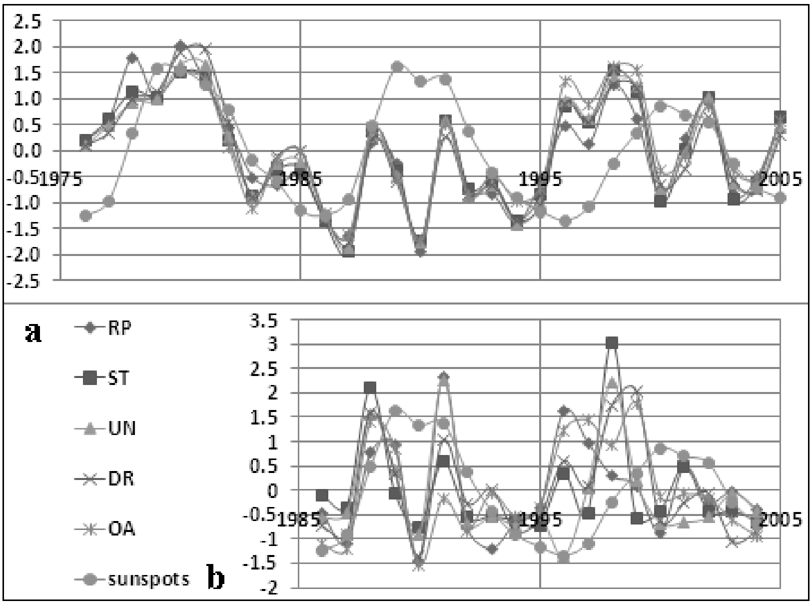


**Fig. 10.** The correlation between sunspots and liquid flow rates (a) and solid flow rates (b) per solar cycles (normalised values).

At Prut Basin latitudes, the clearest multiannual correlation discharge-sunspots can be identified for the period of the year focused on the summer solstice (June, the longest day: over 15 hours, sun angle of incidence with the largest daytime values, of over 66° (Erhan, 1979)). For this reason and because MJJ months have the highest annual percentage of rainfall, MJJ was considered the most representative group of months in order to verify the link between sunspots and flow.

Thus, the flows averaged for the 3 months period of MJJ which equalised or exceeded at Oancea the flows from upstream stations have a correlation with the large number of sunspots of 100% for the liquid flow and 78% for the solid flow rates (sunspots number is considered high when it exceeds the average for the 1976-2005 period). The correlation decreases to 66% for fluid flow and 62% for solid flow when we analyse all months of the year. This shows that the other months of the year have far fewer matches of the flow increases at Oancea (relative to the upstream stations) with solar cycles, mainly due to the gradual melting of snow during the spring from south (Oancea) to north, which determines higher FMA flows at Oancea station.

## 5. Conclusions

The spatial and temporal analyses indicated that the flows of Prut River do not have a classic growth upstream to downstream, but many inflections, in both annual and monthly averages. The causes of these fluctuations are particularly of climatic nature, but of geological and anthropogenic nature also. Oancea hydrometric station shows a very different behaviour from the rest of the analysed stations and, at the same time, very varied. The causes of these variations can be generally explained by different climate characteristics of the lower sector of Prut River Basin and especially by the influence of the solar cycles on the flow regime.

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