THE MOST IMPORTANT HIGH FLOODS IN PRUT RIVER'S MIDDLE COURSE-CAUSES AND CONSEQUENCES

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Abstract

Hydrological risks phenomena on Prut River's middle course are a consequence of the global climate change or variations at the regional and planetary level and secondly, the human intervention in the specific landscape. Statistical analysis focused on the maximum flows recorded at Radauti – Prut, Stanca-Aval, respectively at Ungheni emphasized the multiannual maximum flow variability during 1978 – 2012. The analysis of monthly maximum flows indicates spacial differences caused by local conditions and climatic characteristics of the periods in which they occurred. For the Prut River, the highest flow recorded in the period 1978 – 2012 was 4240 m³ /s at Radauti – Prut in July 2008, as a result of heavy rainfall which fell in Ukraine. The spacial location of the Stanca – Costesti reservoir on the middle course of the Prut river outlined a downward trend of the flows recorded at the hydrometric stations located downstream, due to the mitigating role. Upstream is highlighted a clear upward trend,knowing that the flood peak from 2008 exceeded the flow with the probability of 1 %. Floods study is an important aspect, also the infrastructure monitoring of water resources because they are unevenly distributed and equipped in the middle course. It is necessary to ensure the consistency between quantitative and qualitative management policies applied in Romania, Moldova and Ukraine. Anthropogenic intervention in the Prut river basin triggered negative reactions, and these major imbalances made the floods to emerge stronger.

Key words: flood, variability, risk, maximum flow

The geopolitical importance of the Prut basin is that the river which drains this area is the eastern border of the European Union and NATO. Prut River is a first order left tributary of the Danube and springs in the north – eastern side of the Cerna - Hora ridge (Wooded Carpathians - Ukraine), at an altitude of 2068 m. In Ukraine, Prut river has a total length of 251 km and 695 km forms the natural border between Romania and Moldova. The studied area is characterized by a temperate climate with excessive influences. Knowing the floods' genetic factors, this paper proposes an analysis of their frequency in the last 35 years on the middle course of the Prut River

MATERIAL AND METHODS

Statistical analysis focused on the maximum flows recorded at Cernauti, Radauti – Prut, Stanca-Aval, respectively at Ungheni outlined the multiannual maximum flow variability during 1978 - 2013.

For the maps with the average rainfall distribution and multiannual mean flow was used ArcGIS software and recorded data at the pluviometric and hydrometric stations on the studied area. Angot rainfall index (k) was calculated to highlight the characteristics of monthly rainfall variation. It revealed also a seasonal growth trend in spring and summer of 2008 and 2010 on Prut Rive's middle course.

The major floods occurred upstream and downstream of Stanca – Costesti reservoir were cought on the hydrographs of flows recorded in a three – hour interval.

RESULTS AND DISCUSSIONS

The occurrence of floods is primarily due to the natural factors related to climatic conditions that generate large amounts of rainfall (Degre A. et al., 2013). They induce the growth of levels or flows higher than normal and the overflow of waters in the adjacent areas. The land field affected by floods depends on width of the riverbed, earth variation rates in the river floodplain respectively, high water level, flow and duration of the flood

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wave (Hancu S. et al, 1971) .

Studies undertaken by the Intergovernmental Commission on Climate Change and the European Environment Agency shows that rainfall increased with 10 - 20 % after 1975 in Romania, as in other regions of Europe. The average temperature at the Earth's surface has increased with 0.6° C in the last century and the development was three times faster since 1975. If the thermal regime predictions can be made, with some degree of certainty, the rainfall regime is random, with a high degree of unpredictability.

The spatial distribution of the average rainfall (*figure* 1*)* shows that in the extreme north of the studied area rainfall amount is higher (Darabani 775 mm), and in the north - east does not exceed 550 mm (Radauti - Prut, Stanca - Aval).

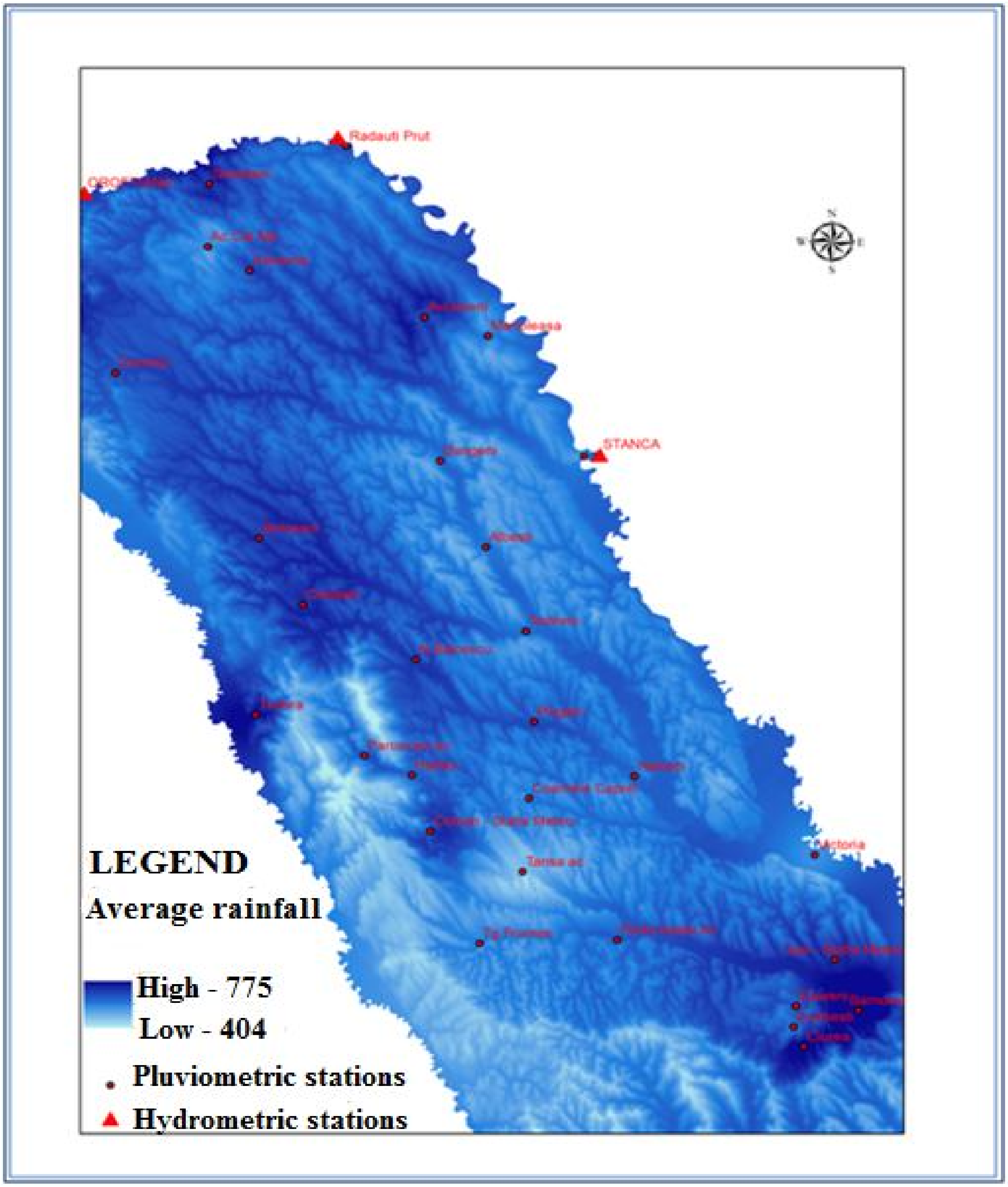


Figure 1 **The map with the average rainfall distribution**

Prut River floods in 2008 and 2010 were caused by heavy rainfall in the upper basin (Wooded Carpathians - Ukraine) and in the middle one.

Total monthly values recorded in July 2008 at the rainfall stations in the observed area are : 168 mm (Oroftiana), 161.1 mm (Radauti - Prut), 119 mm (Ungheni). In 2010, significant rainfall quantities have fallen since May – 89.5 mm, in June - 277 mm, in July – 124.8 mm at Oroftiana. At Radauti – Prut were recorded in the same year 103.2 mm in May, 165 mm in June and 149.9 in July. At Ungheni rainfall station , total monthly value which interests was reached in June 2010 (115.4 mm).

Angot rainfall index (k) was calculated to highlight the characteristics of monthly rainfall variation. At the stations along Prut River: Oroftiana, Radauti –Prut and Ungheni is characteristic the type represented by supraunitary values in April – July and subunitary values in the period from November to March at Oroftiana or Radauti – Prut, and in August, October, November and March at Ungheni. Supraunitary values characterizing June, July and August indicate a rainy period on the middle course of the Prut River: at Oroftiana pluviometric station k > 1 in April (1.26), May (1.89), June (2.04) or July 2008 (3.14) and in 2010 k > 1 in June (1.52) and July (3.31). Angot index variation at the two pluviometric stations keep the same seasonal growth trend (spring and summer) in 2008 and 2010. At Radauti-Prut hydrometric station the multiannual average flow for the period 1978 – 2012 was 86 m^3/s. In 2008 and 2010 the annual average flow was 137 m^3/s and 156 m^3/s, values much higher than the module flow. At Stanca – Aval hydrometric station the multiannual average flow calculated for the same period is 88 m^3/s. Annual values of 2008 and 2010

Maximum flow, through the special effects that prints on the hydrological regime, is the most important phase of it. However, in this stage of treatment, the most spectacular as evolution, effects and volume of water transported are the floods (Beighley R. E. et al, 2005).

Data analysis of the maximum flow recorded at the hydrometric stations located on the Prut River shows that they came from the rain and are the largest in the whole period of observations.

Upstream hydrometric records have an obvious upward trend and downstream, due to the attenuation role exercised by the reservoir, the trend is downward.

There is a consensus that hazards resulting from hydrological extremes are on the increase. This fact is confirmed by evidence both for recent changes in the frequency and severity of floods as well as droughts and for outputs from climate models which predict increases in hydrological variability (Fuchs *et al.*, 2009).

The multiannual variability of maximum flow recorded on the Prut River, highlights significant values in 1981, 1988, 1991, 2005, 2008 and 2010 at the all hydrometric stations located along the Prut River, on the sector we studied . An elaborate analysis of the maximum monthly flow values recorded at the three stations : Radauti – Prut, Stanca – Aval and Ungheni indicate spatial differences caused by local conditions or rainfall and thermal characteristics of the periods in which they occurred. Maximum values in June and July have a high frequency of occurrence (56%), followed by the period April – Mai (25.7 %).

On the Prut River, the largest value recorded in the period 1978 – 2012 was 4240 m^3/s at Radauti – Prut hydrometric station in July 2008, exceeding the flow with the probability of 1 % (3806 m^3/s). The values corresponding to the maximum flows of 1988, 1991, 2005 and 2010 have the probabilities between 2 % and 10 %.

The impact of the flood in Radauti – Prut section, in 2008, was due to the aggregation of two contrary forces : the flood wave coming from Ukraine territory and the remuu wave originated in the lake, which was propagated upstream on a distance of 70 km (Romanescu et. al, 2011).

Basically the flood began on July 24, 2008 at Cernauti, where the flow jumped to 387 m^3/s and the level exceeded the warning rate (314 cm) with 186 cm. In the same day at Radauti – Prut hydrometric station was registered the level of attention - 290 cm and a maximum flow of 434 m^3/s. During three days the level reached 1088 cm, + 488 cm above the danger level and was maintained until July 30, 2008 (803 cm).

In 2010 at Cernauti hydrometric station the level increased in 24 hours from 117 cm to 412 cm (June 23, 2010), value corresponding to a flow of 677 m^3/s. The maximum flow registered in 2010 was 2070 m^3/s (July 10), when the level reached 645 cm.

At Radauti-Prut station, in 2010, the warning lever was exceeded since June 24 (460 cm) and the danger level on June 25 (612 cm, + 12 cm above danger level), June 29 – 688 cm, June 30 – 685 cm. On July 1st the level reached 709 cm (109 cm over danger level), level corresponding to a flood peak of 2137 m^3/s. Downstream the flood elevation was exceeded on June 27 (301 cm), and the danger level on June 30 (383 cm, 8 cm above the danger level). The maximum level reached at Stanca – Aval 459 cm (+84 cm over danger level) on July 3, corresponding to a flow of 879 m^3/s.

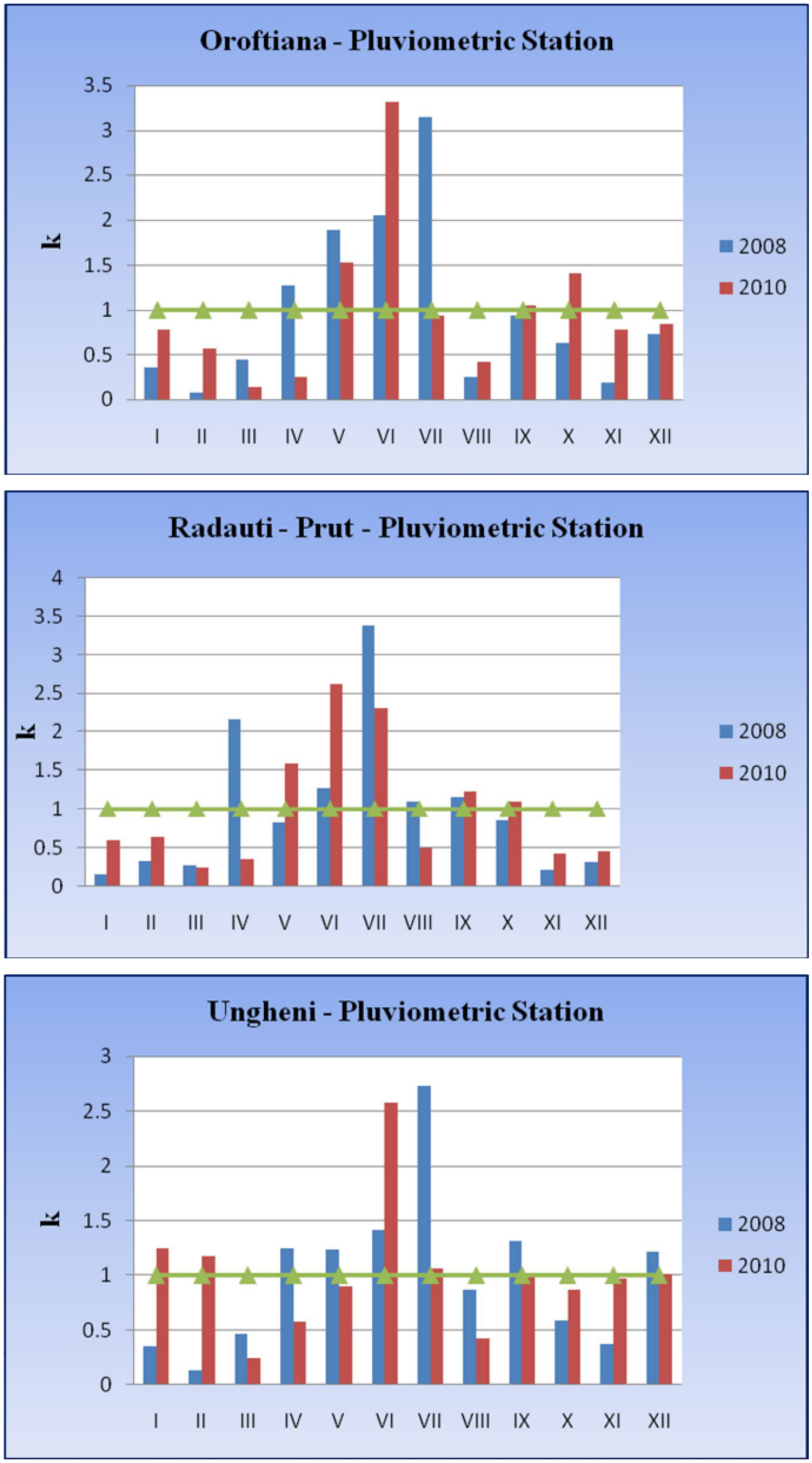


Figure 2 **Angot monthly rainfall index variation in 2008 and 2010**

Stânca – Costesti reservoir is located on the middle course of the Prut River. At the normal retention level it has an area of 5900 ha, a maximum volume of 1400 mil. m^3 and a length of 7 km. At the maximum level it has an area of 9200 ha and a total length of 90 km. The flow calculation providing 0.1 % is 1530 m^3/s and corresponds to a level of 99.50 m.

In 2008 and 2010 the maximum flow recorded at Stanca – Aval hydrometric station was

1050 m^3/s and 885 m^3/s (higher values than the probability flow of 10 % - 745 m^3/s). For the floods with minor importance and also for the one with the probability of 1 % , the flow discharged downstream from the reservoir have the same size, 600 – 700 m^3/s.

The flood control is achieved by the tranche of 550 mil. m^3, volume that can be in the accumulation between the normal level of retention and the rate of the tilting – gates in the "closed" position and the tranche of 115 mil. m^3/s located above the upper edge of the tilting – gates.

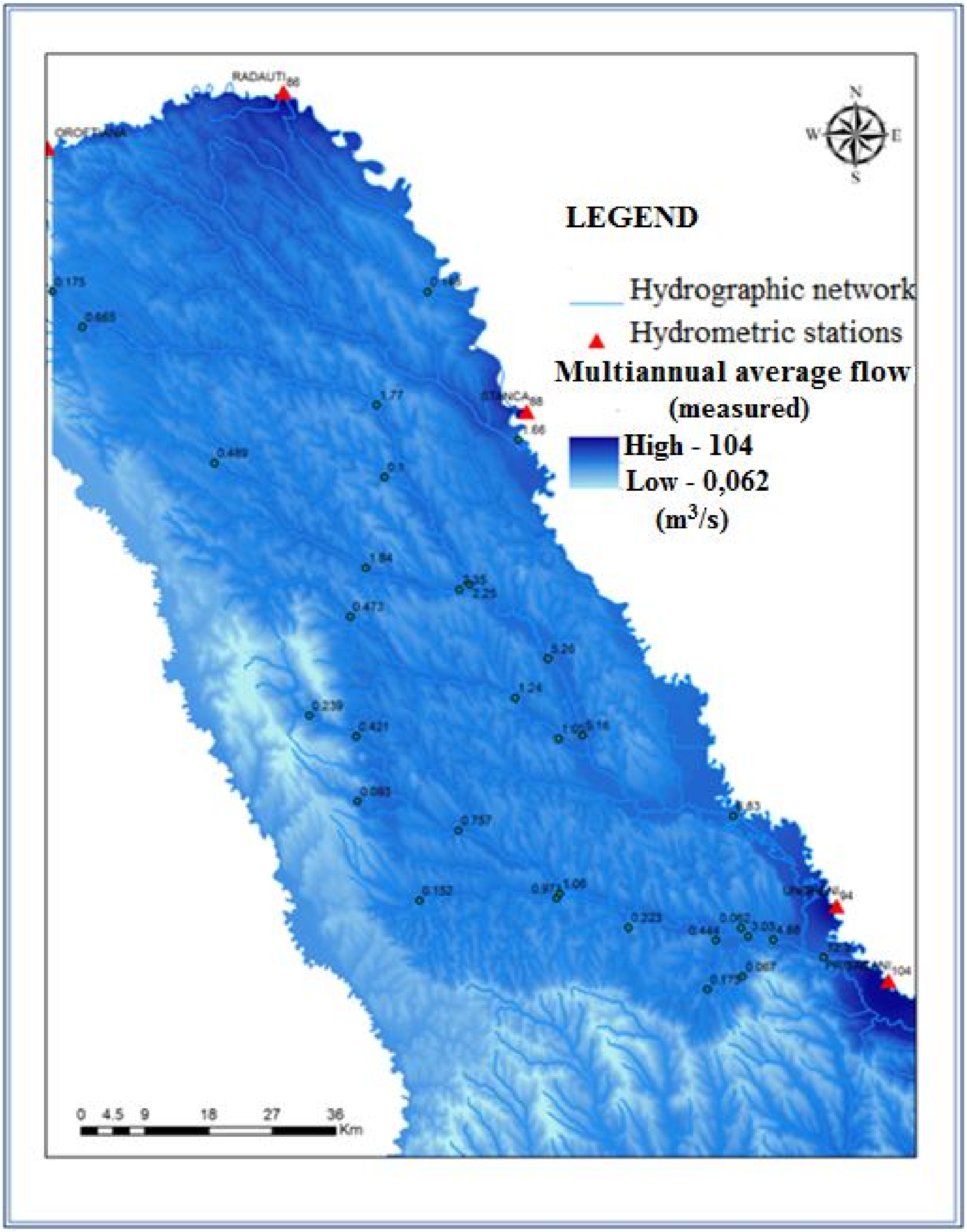
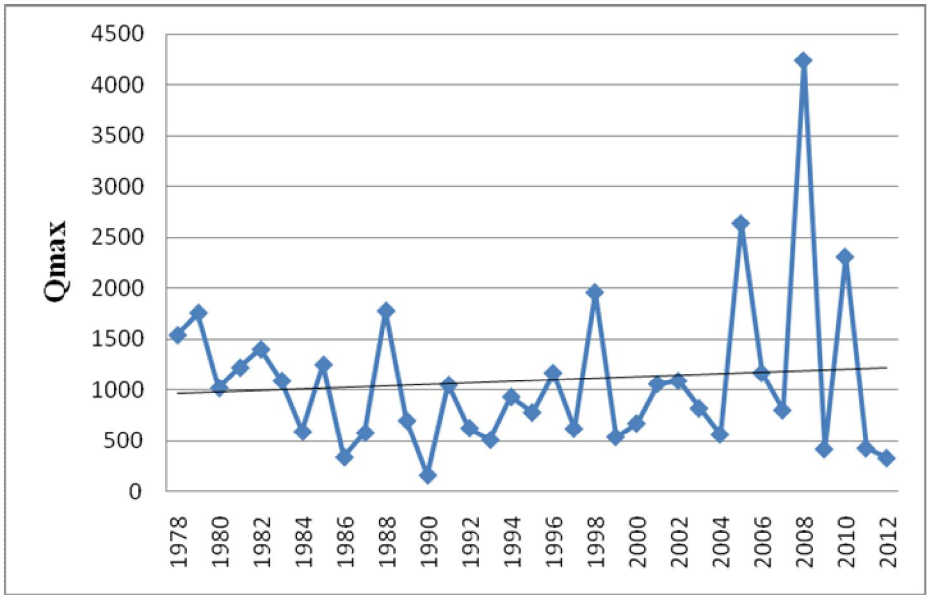
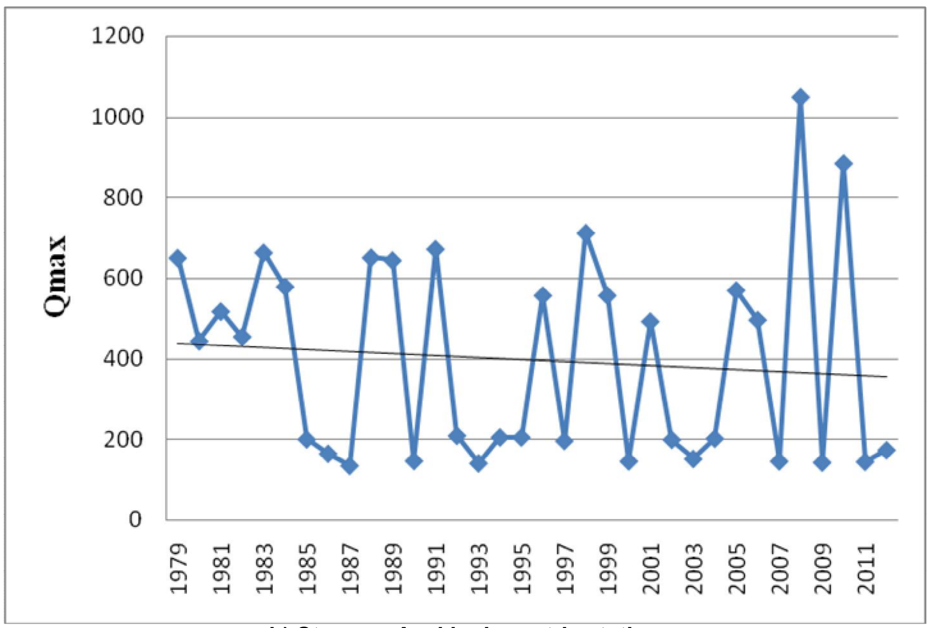


Figure 3 **Multiannual average flow distribution map**



a) Radauti – Prut hydrometric station



b) Stanca – Aval hydrometric station

Figure 4 **The variability of multiannual maximum flows during 1978 – 2012**

Under the conditions of high water level, the discharged flow exceeds 300 m^3/s , and the lake level overtakes the rate of 90.80 m. Water supply to the uses is done through the turbinate flows in the two power plants, and the transport capacity of the riverbed downstream is 500 – 550 m^3/s. Partial emptying can be done through the reserve waterintake (40 – 70 m^3/s) and through the complete opening of the two bottom emptying, including the lateral draining, in this case the evacuated flow will be 600 – 700 m^3/s. The flow should not exceed 700 m^3/s in Ungheni section, where the floods on Jijiacould have a significant contribution.

In case of the propagation to a flood with the flow corresponding to a probability of 1 % (3806 m^3/s in Radauti – Prut section), such as the flood of 2008, downstream the maximum flow will not increase above 700 – 765 m^3/s, and in the reservoir will not exceed the maximum level of 98.20.

Flood mitigation is at the crossroads of different policies (agriculture, environment, land use planning, and water management) (Evrard O.*et al.*, 2010).These function of Stanca – Costesti reservoir is undeniable, but the hydrostatic pressure exerted on the dam was manifested a long period (20 – 30 days) in 2008 and 2010 and the stored water volume reached the probability of 0.1 %. In the late July 2008 the water level values in the lake were 98.21 m (July 30, 2008) and 98.20 m (July 31, 2008) and the maximum volume retained was 745 mil. m^3. In 2010, values that exceeded the gross volume of the reservoir at normal retention were recorded since June and in July reached 1244.30 mil. m^3. High volume values were maintained until the end of August , 776.73 mil. m^3 on August 31, 2010.

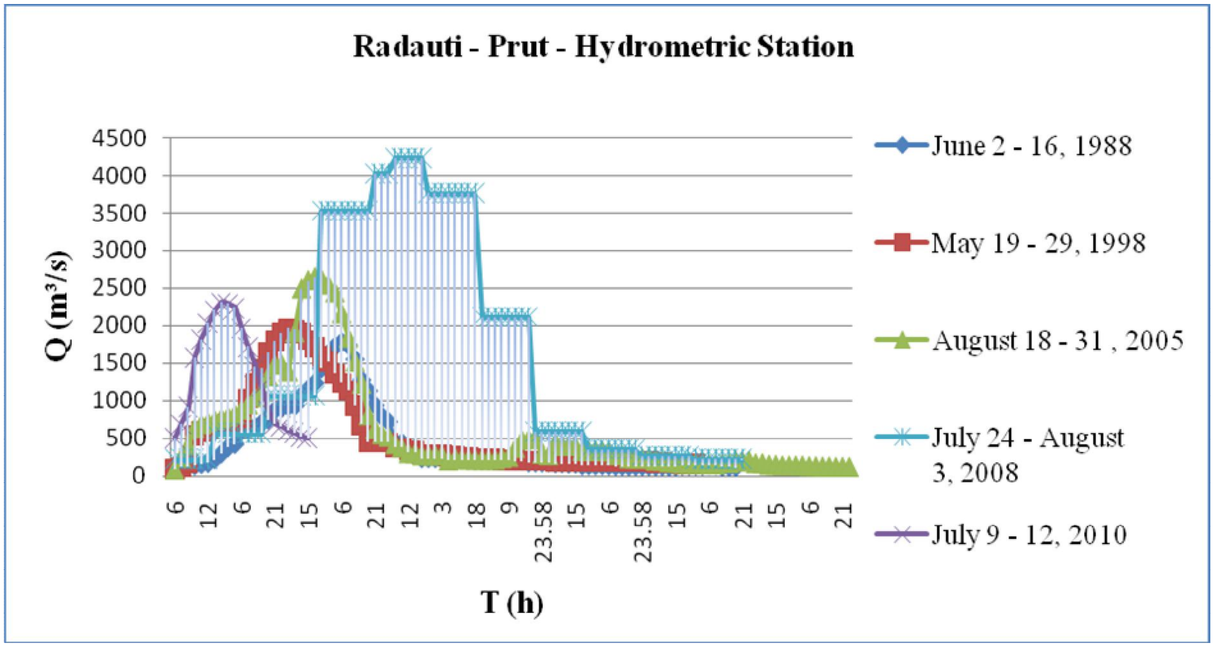


Figure 5 **Major floods occurred upstream of Stanca – Costesti reservoir**

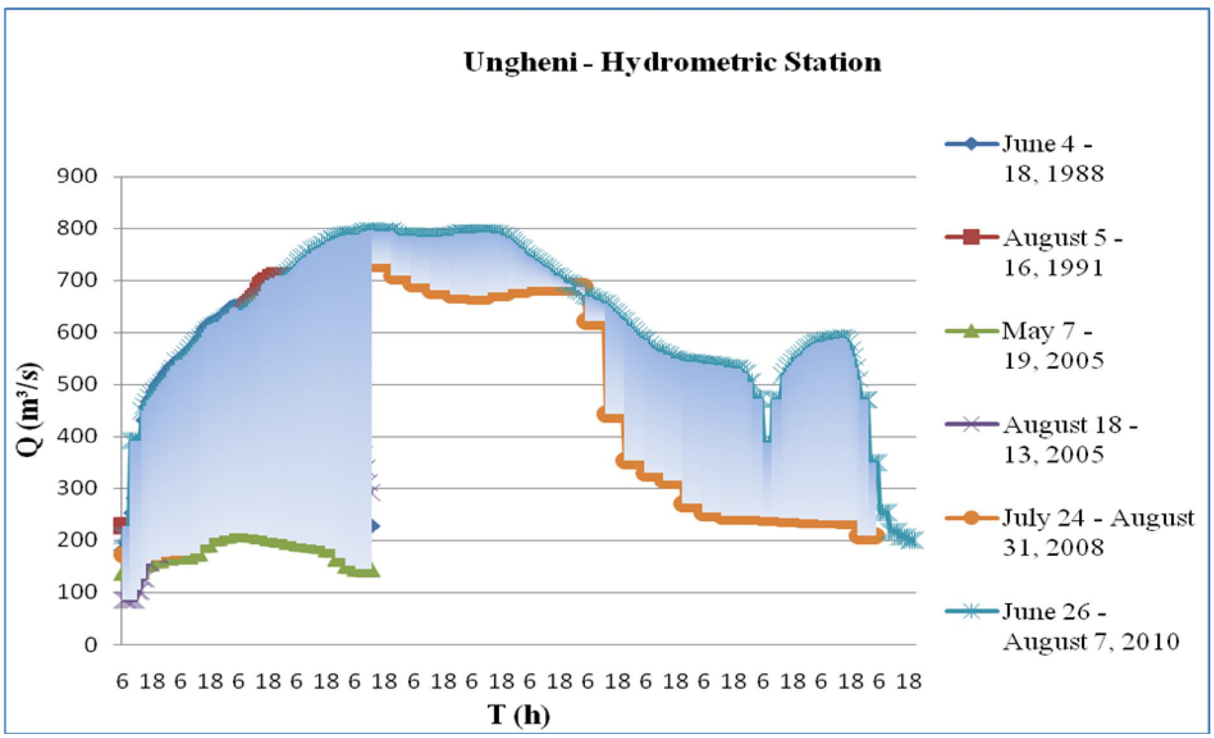


Figure 6 **The main floods occurred at Ungheni hydrometric station**

At Ungheni hydrometric station, the hydrograph with the last 5 floods, presents flow values higher than 700 m^3/s on August 13 , 1991 (710 m^3/s), August 5, 2008 (748 m^3/s) and from 4 July (707 m^3/s) to July 18 , 2010 (703 m^3/s). In 2010, was exceeded the flow with the probability of 1% on July 8 and 9, when the value of 796 m^3/s was recorded , respectively on July 14 and 15, when it reached 792 m^3/s. The interval of this flood event was from June 26 to August 7. The flood wave has been propagated slowly downstream due to the low slope (0.4 – 0.2‰) of Prut River and the control of discharged flow from Stanca – Costesti reservoir.

Floods in the area between Stanca – Costesti accumulation and Prut confluence with the Danube were amplified by unauthorized exploitation of gravel from the riverbed and the repeated deforestation on the basin slopes or on the longitudinal alignment of the levees.

It is estimated that the damage caused by the floods are 20% lower as a result of the warning and the hydrological forecast (Diaconu C. D. et al., 2009). Providing these means, significant historical events on the Prut River occurred in July – August 2008 , affected the settlements located downstream of Oroftiana and upstream of the Stanca – Costesti reservoir, downstream and upstream of Gorban respectively, an area of 51830 km² Two years later, in June – July 2010 were flooded 36543 km².

CONCLUSIONS

Climate variations at the planetary and regional level, as well as the anthropogenic intervention in the studied sector of the river, favored the manifestation of floods in 1985, 1988, 1991, 1998 and 2005. In July – August 2008, a total area of 51830 km² was affected, and in June – July 2010 – 36543 km².

Prut River floods in 2008 and 2010 were caused by the heavy rainfall in the uppercourse (Wooded Carpathians – Ukraine) and in the middle one.

Supra-unitary values of Angot monthly rainfall index characterizing spring and summer indicate a rainy period in the middle course of Prut River in the two years we studied.

Building the Stanca – Costesti reservoir on the middle course of the Prut River reduced the frequency of floods in Romania. Judicious exploitation of the hydrotechnical construction and the draining operations played an important role in the transit of the flood waves and reduced the negative effects.

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