RIVER FLOW REGIMES ON RIVER SAVA SLOVENIA 1961 – 2000

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Abstract: River flow regime is one of the basic river characteristics. Primary it is dependant upon physical geographical characteristics and also upon socio geographical characteristics of the catchment area. Time, period and space changes in Sava's flow are mostly the result of climatic and landscape characteristics of the upper and the middle catchment area of the Sava River. The paper shows present classifications of the Sava flow regimes and the comparison of the WMO reference period 1961-1990 and the last 20th century period 1991-2000. The differences and changes can be understood as part of the impact of climatic changes.
Keywords: river flow regime, discharge regime, hydrogeography, cluster analysis, Slovenia, Sava River

ABFLUSSVERHÄLTNISSE DER FLUSS SAVA IN SLOWENIEN 1961 – 2000

Zusammenfassung: Abflußregime ist eine der grundlegenden Flußeigenschaften. Hauptsächlich ist es nach physicalisch geographischen Eigenschaften und auch nach soziologisch geographischen Eigenschaften des Einzugsgebiets abhängig. Zeit-, Perioden- und Raumänderungen im Fluß sind meistens das Resultat der klimatischer und Landschaftseigenschaften des oberen und mittleren Einzugsgebiets des Sava Flusses. Die anwesenden Klassifikationen der Untersuchungen der Sava Flußregime und der Abflussverhältnisvergleich des WMO fraglichen Zeitraums 1961-1990 und der letzten Jahrhundertperiode 1991-2000. Die Unterschiede und die Änderungen können als Teil der Auswirkung der klimatischen Änderungen verstanden werden.
Schlüsselworte: Flußabflußregime, Entladung Regime, Hydrogeographie, Blockanalyse, Slowenien, Sava Fluß

1. Introduction

The Sava River is the longest Slovenian stream. The river is formed when two major tributaries, Sava Bohinjka and Sava Dolinka merge into one Sava River near the city of Radovljica. From the Spring of Sava Dolinka in Zelenci the river flows 947 km into the Danube (ARSO, 2003a). In Slovenia the Sava Dolinka has 44 km, Sava Bohinjka 41 km and the merged Sava flows 175 km until the border with Croatia where it drainages almost 11.000 km^2. The total length in Slovenia is therefore 220 km with the springs on 883 m and outflow on 132 m above the sea level. The article relates on the river flow analysis of the WMO reference period 1961-90 and the last decade 1991 – 2000. In the overview we tried to prove the influence of climate changes for the river flow regimes.

River flow regime describes the average seasonal behavior of the river flow (Krasovskaia, 2000, p. 1). The regime depends on the amount of water, precipitation, temperature and other climatic factors (Streamflow, 2003, p. 1). Besides these major factors we must take into consideration also other physical-geographical factors, especially the relief, vegetation and the human impact (Hrvatin, 1998, p. 81). Flow regime is therefore the product of the watershed geographical characteristics and climatic dynamics (Newmarch, 2003, p. 1). We can assume that the major driving force on the river flow is climate (and its changes), because the secondary driving force – relief – is practically constant (Frantar, 2003). Temperature, as a subpart of the climate, has the biggest influence on the flow (Plut, 2000, p. 70). Due to all this mentioned factors of influence, the river flow regime is a part of hydrological –storm indicators of climatic changes (Houghton et al, 2001).

The first attempts to describe river flow regimes were made by Russian Voeikov in the 19th century. In 1884 he made classification of 9 global regime types. Systematic monitoring and growing hydrological knowledge led to one of the most known hydrological flow regime classifications – the Parde classification (Krasovskaia, 2000, p. 2). In 1933 Parde first used the flow coefficients (abr. **fc**) which allow the independent comparison between the rivers with different flow amounts (Ibid., p. 3). The basic Parde classification consists of three regime types: simple, complex-original and complex-changing. Most of the past classifications consider in the analysis besides the climate also the source of seasonal extremes. Until the »computer age« the analysis based usually on subjective comparison of river flows.

In Slovenia the first river flow regime analysis is a part of wider research of flow regimes in Yugoslavia in 1947 (Ilešič, 1947). In 1987 the map of Slovenian river flow regimes was created by Stele (Pristov, 1987; Hrvatin, 1998, p. 82) and in 1998 Kolbezen made the classification based on 30 year period (Kolbezen et al., 1998, p. 26) and in the same year Hrvatin completed the newest classification of Slovenia's rivers. The 8 main types were obtained with hierarchical clustering using Ward method also for the 30 year period. From all these papers we can find out these classes of Sava river flow regime:

Table 1: Flow regime types on Sava River in previous research papers (sources: Ilešič, 1947; Pristov, 1987; Kolbezen et al, 1998; Hrvatin, 1998)

Author	*River flow regime type*	*Geographical zone*
Ilešič	*nivo-pluvial – alpine variant*	*upper stream (Radovljica)*
	pluvio-nival, middleeuropean variant	*lower stream (Krško)*
Stele	*transitional nivo-pluvial with mediteranian impact*	*Sava Dolinka*
	nivo-pluvial	*Sava Bohinjka and Sava in Radovljica*
	pluvio-nival with moderate mediteranian impact	*Sava lower stream*
Kolbezen	*nivo-pluvial*	*Sava upper stream, upstream from the Kamniška Bistrica inflow*
	pluvio-nival	*Sava lower stream, downstream from the Kamniška Bistrica inflow*
Hrvatin	*alpine high mountain nivo-pluvial*	*Sava Bohinjka, Sava Dolinka and Sava in Radovljica*
	alpine medium mountain nivo-pluvial	*Sava in Šentjakob*
	alpine pluvio-nival	*Sava downstream from Litija*

After all this research overviews we find out that Sava river belongs to second Parde type – known also as mixed river flow regime. Common in all research papers (based on flow data until 1990) we find out that: **Sava River in upper stream has nivo-pluvial river flow regime (upstream from Litija respectively upstream from the Kamniška Bistrica and Ljubljanica inflow), and in the downstream part its flow regime becomes pluvio-nival type.**

2. Methodology

Since the early 20th century, many water gauging stations have been working on river Sava. We have selected eight stations with good dataflow from year 1961 until 2000. Due to reallocation of stations, two of the water gauging locations had to be specially calculated and also some data problems must be mentioned:

- Stations Podkoren and Kranjska Gora were merged with their flow coefficients so we can have the full period coefficient data.
- Station Jesenice has missing monthly data in years 1976 and 1977.
- Station Radeče was in use until 1996. After that, due to the dam of HP Vrhovo, the station data are calculated with the sum of 2 stations Hrastnik on Sava River and Veliko Širje on Savinja River.

Table 2: Selected water gauging stations on river Sava (source: ARSO, 2003a)

	Water gauging station	*Flow data since*	*Length from spring in km*	*Watershed in km2*
1	*Podkoren (Kranjska Gora)*	*1959 oz. 1991*	*1*	*30 (45)*
2	*Jesenice*	*1952*	*28*	*258*
3	*Sv. Janez*	*1959*	*8*	*94*
4	*Radovljica*	*1945*	*39*	*908*
5	*Šentjakob*	*1957*	*100*	*2.276*
6	*Litija*	*1927*	*129*	*4.821*
7	*Radeče*	*1945*	*163*	*7.083*
8	*Čatež*	*1956*	*210*	*10.186*

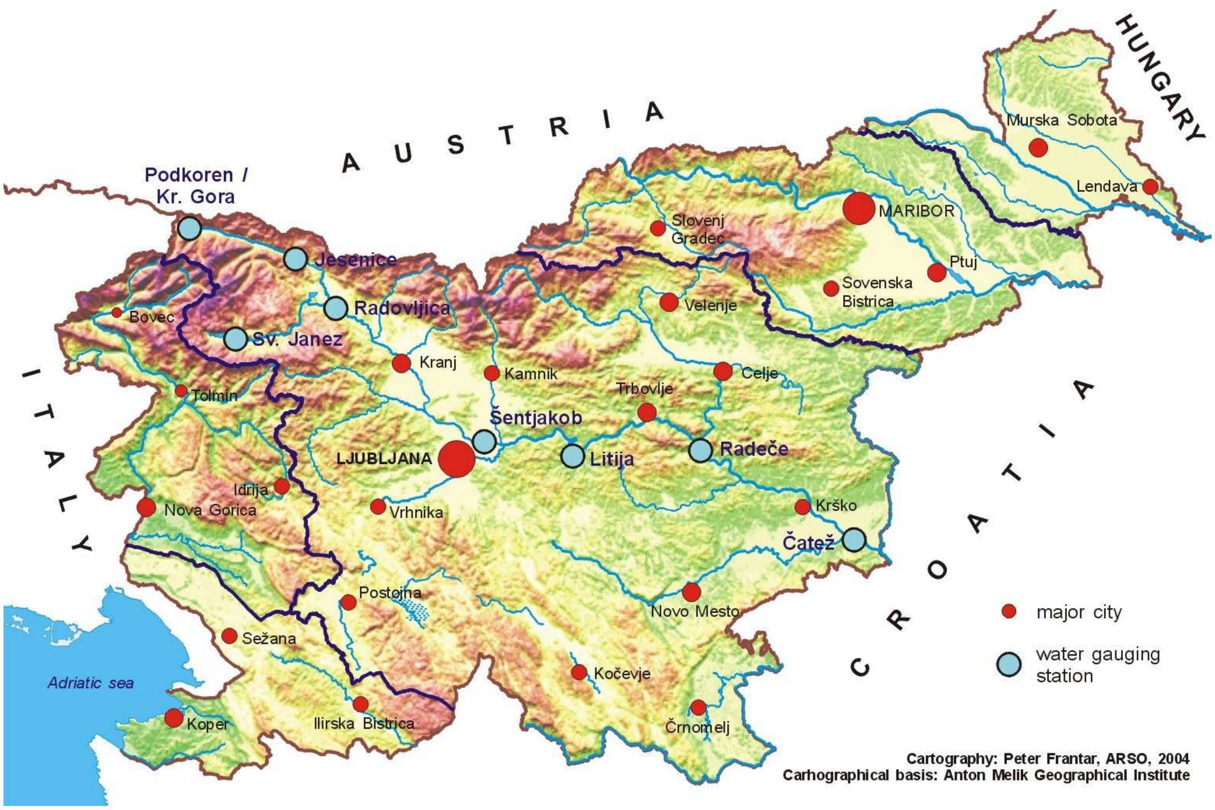


Figure 1: Locations of water gauging stations on Sava River

The analysis of the river flow regimes was done with statistical approach. We used the hierarchical clustering method to create »groups«. The method can be modified with many different classification algorithms which can be used to create a good taxonomy. Basic classification principle is: the higher the aggregation level is, the less similar are the objects in a certain class are (StatSoft, Inc., 1998). We evaluated many algorithms and sub methods and come to the conclusion that the same process, as used by Hrvatin, is the most appropriate: (Hrvatin, 1998, p. 83): Ward amalgamation rule with City-block (Manhattan) distance measure (Ibid.).

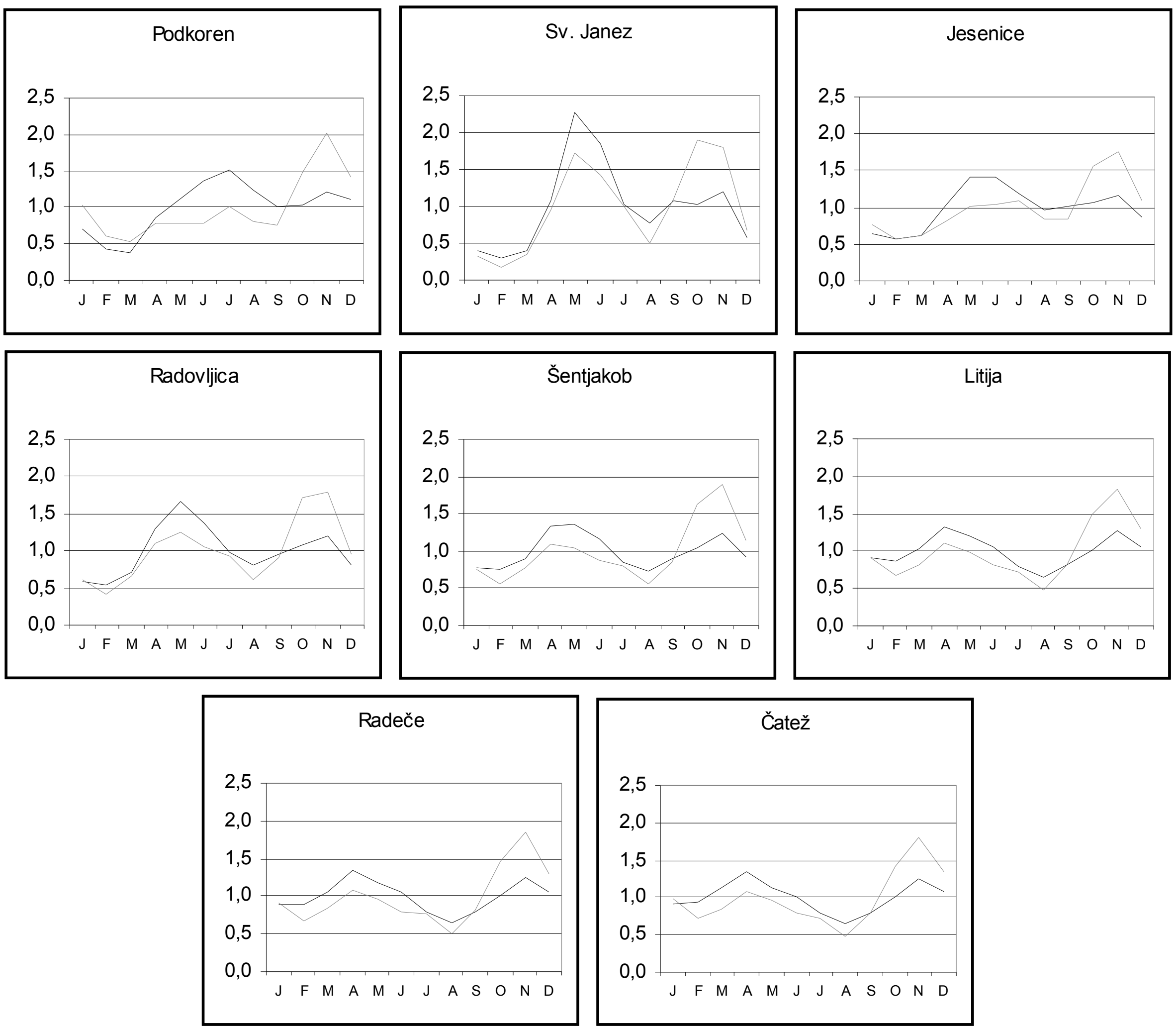


Figure 2: Average monthly flow coefficients for individual water gauging stations on river Sava. Black line marks period 1961-90, gray line marks period 1991-2000 (source: ARSO, 2003b)

3. River flow regimes analysis

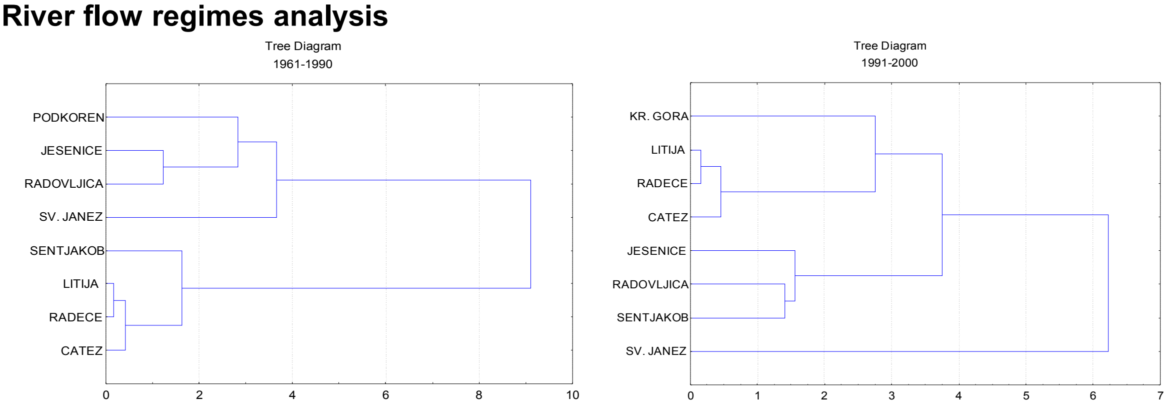


Figure 3: Tree diagram of hierarchical clustering for 2 periods for selected water gauging stations

3.1. Period 1961-1990

Table 3: Monthly river flow coefficients for period 1961-1990 (source: ARSO, 2003b)

	JAN	*FEB*	*MAR*	*APR*	*MAJ*	*JUN*	*JUL*	*AVG*	*SEP*	*OKT*	*NOV*	*DEC*
Podkoren	*0,71*	*0,43*	*0,37*	*0,86*	*1,11*	*1,36*	*1,53*	*1,23*	*1,02*	*1,04*	*1,21*	*1,10*
Sv. Janez	*0,39*	*0,29*	*0,40*	*1,08*	*2,27*	*1,85*	*1,01*	*0,78*	*1,09*	*1,02*	*1,20*	*0,58*
Jesenice	*0,64*	*0,56*	*0,62*	*1,05*	*1,41*	*1,41*	*1,20*	*0,96*	*1,01*	*1,05*	*1,15*	*0,87*
Radovljica	*0,60*	*0,55*	*0,71*	*1,29*	*1,65*	*1,37*	*0,98*	*0,80*	*0,96*	*1,08*	*1,20*	*0,80*
Šentjakob	*0,78*	*0,75*	*0,91*	*1,33*	*1,35*	*1,16*	*0,86*	*0,73*	*0,89*	*1,05*	*1,25*	*0,93*
Litija	*0,90*	*0,87*	*1,04*	*1,33*	*1,19*	*1,06*	*0,78*	*0,65*	*0,82*	*1,02*	*1,28*	*1,07*
Radeče	*0,89*	*0,88*	*1,07*	*1,35*	*1,17*	*1,07*	*0,80*	*0,65*	*0,80*	*1,02*	*1,26*	*1,06*
Čatež	*0,91*	*0,93*	*1,13*	*1,35*	*1,12*	*1,02*	*0,79*	*0,64*	*0,79*	*1,00*	*1,25*	*1,08*

In the river Sava flow analysis, in the reference period 1961-1990, we determined the following clusters of water gauging stations: 2 groups that coincide highly with previous research results. The upper stream of Sava river has nivo-pluvial and the lower stream has pluvio-nival river flow regime. The difference between the regimes from the previous researches is that the flow regime in Šentjakob has more in common with the regimes downstream than with the regimes upstream. On water gauging stations Podkoren, Sv. Janez, Jesenice and Radovljica we have nivo-pluvial and in Šentjakob, Litija, Radeče and Čatež we have pluvio-nival river flow regime. The results of statistical clustering we can certify also from the image of »raw« flow regimes format in figure 3.

3.1.1. Nivo-pluvial river flow regime type

The main characteristic of this type is distinctive spring high water and quite lower fall secondary high water. The winter low is primary and the secondary low is summer (Plut, 2000, p. 73). The best expressed nivo-pluvial river flow regime has Sava Bohinjka in Sv. Janez. The primary peak in May and June is, due to the snow melt in the high mountains, very conspicuous and it reaches 2,27 of average annual flow. Secondary high in the fall is the consequence of fall rain and it reaches only 1,2 coefficient. The primary low of the flow is in February (fc = 0,29) and is caused by the snow retinence; secondary low occurs in the summer mostly due to higher evapotranspiration and also due to lower precipitation (k = 0,78). The similarity between the river flow regime in Sv. Janez and other 3 locations of this regime type is lower than it is between the second »subgroup« locations. Distinctive flow regime type also has Sava Dolinka in Podkoren where we can see high influence of rain and snowmelt water. The primary high waters are in July and the secondary are in accordance to fall's precipitation as rain in November. Low waters in Podkoren are in March and September, but the March low waters are below the average annual flow.

Bigger conformity is seen between Jesenice and Radovljica. Primary highs are in May (snowmelt, rain) and secondary highs in November. The May highs are about 1,5 and Novembers about 1,2. The lows are on both locations below the yearly average, where the primary low is above 0,5 yearly averages.

Out of all locations with this regime type the Sv. Janez location has the highest annual fluctuation – between 0,29 and 2,27. All other locations are within the limits of 0,37 in Podkoren and 1,78 in Radovljica.

3.1.2. Pluvio-nival river flow regime type

Typical characteristics of this type are more distinctive summer as winter low waters and equaling of fall high FC to spring high water FC. All four stations are highly connected, but even higher similarity we can find even higher similarity between water gauging stations Litija, Radeče and Čatež. Despite this, the flow regime of Sava in Šentjakob does not show many deviations. Primary high waters are in May (also April's **FC** is almost the same) which indicates to the connection with Jesenice and Radovljica – the high mountains snowmelt waters. Secondary highs are in November. The high waters are almost the same with 1,3 of the annual flow. Flow regime in Šentjakob used to be classified in nivo-pluvial type (Kolbezen et al, 1998; Hrvatin, 1998), but we still must confirm that here the rainwater has the most influence: also the summer low (0,73) is already »lower« as winters (0,75) as a result of lowland snowmelt in February and the summer rain deficit and increased evapotranspiration.
The same yearly flow fluctuations have three »lowland« water gauging stations. The August low is about 0,65 and winter low (January or February) is about 0,9. The high waters in April and November are almost the same: April's some 1,35 and November's some 1,28.

We can establish that on these four water gauging stations the variance between low and high waters are smaller than on upstream stations: between 0,64 and 1,35.

3.2. Period 1991- 2000

Table 4: Monthly river flow coefficients for period 1991-2000 (source: ARSO, 2003b)

	JAN	*FEB*	*MAR*	*APR*	*MAJ*	*JUN*	*JUL*	*AVG*	*SEP*	*OKT*	*NOV*	*DEC*
Podkoren – Kr. Gora	*1,02*	*0,60*	*0,54*	*0,78*	*0,78*	*0,79*	*1,00*	*0,82*	*0,75*	*1,48*	*2,01*	*1,40*
Sv. Janez	*0,32*	*0,17*	*0,36*	*0,96*	*1,73*	*1,42*	*1,01*	*0,50*	*1,11*	*1,89*	*1,81*	*0,69*
Jesenice	*0,76*	*0,57*	*0,62*	*0,83*	*1,01*	*1,03*	*1,08*	*0,83*	*0,84*	*1,56*	*1,76*	*1,10*
Radovljica	*0,61*	*0,42*	*0,65*	*1,09*	*1,24*	*1,04*	*0,93*	*0,62*	*0,91*	*1,72*	*1,78*	*0,95*
Šentjakob	*0,76*	*0,55*	*0,77*	*1,10*	*1,05*	*0,87*	*0,81*	*0,56*	*0,86*	*1,62*	*1,89*	*1,14*
Litija	*0,91*	*0,67*	*0,82*	*1,10*	*0,99*	*0,82*	*0,73*	*0,49*	*0,81*	*1,49*	*1,84*	*1,30*
Radeče	*0,92*	*0,68*	*0,83*	*1,08*	*0,97*	*0,80*	*0,76*	*0,51*	*0,81*	*1,48*	*1,84*	*1,30*
Čatež	*0,98*	*0,72*	*0,85*	*1,09*	*0,97*	*0,80*	*0,71*	*0,48*	*0,80*	*1,43*	*1,80*	*1,36*

In years after 1991 we conducted the same analysis of river regimes, but the results were different (figure 3), 3 groups:
- The first group is only the Sv. Janez water gauging station,
- The second group form stations Jesenice, Radovljica and Šentjakob,
- The third group consists of Litija, Radeče, Čatež, and also (astoundingly) Kranjska Gora.

The Sava Bohinjka in Sv. Janez has pluvio-nival river flow regime. The snow retinence is still the cause for the primary minimum in February that limits the flow to 0,17 of yearly average. The snow is still the cause for melt water which leads to secondary maximum (in 1961-90 was primary maximum!) in May with coefficient value of 1,73. Secondary minimum is in August with 1,5 value and primary maximum is now in fall with 1,89 average annual flow. As we can see from this monthly river flow behavior the regime in the last decade has become rainier, but is still influenced by the effects of low winter temperatures in high mountains. The characteristic of the river flow regime of river Sava in Sv. Janez we now may specify as ***high mountain pluvio-nival type***.

Second group is formed from the flows in Jesenice (Sava Dolinka), Radovljica and Šentjakob. All flow regimes in these water gauging are highly connected. The primary extremes of the flow regimes are: high waters in fall, in November; the low waters in winter, in February. The fluctuation of the river flow regime in Jesenice is between 0,57 and 1,76 and is less than on the stations Radovljica and Šentjakob – which varies from 0,42 to 1,89. Secondary low is on all the stations is at the end of the summer; but secondary high waters are very different: in Jesenice in July, in Radovljica in May and in Šentjakob in April. It is the consequence of different year period with the snowmelt water due to different relief characteristics. The secondary extremes in Jesenice are very blurry. Finally we can state that this river flow regime has even more rain influence as Sv. Janez and the snow influence is diminishing, so we can specify this regime as ***medium mountain pluvio-nival type***.

The third group »objectively« calculated includes three stations with very short statistical distance: Litija, Radeče and Čatež, where the river flow regimes are almost identical. The primary maximum is in November with 1,84 and secondary in April with 1,1 annual flow. The low water coefficients are very similar, primary with 0,5 in August and secondary with 0,7 in February. Compared with the annual precipitation scheme the flow on these locations is even rainier. The name of the regime is ***lowland pluvio-nival type***.

As we can see (Figure 3) the station **Kranjska Gora** is also in the cluster with three lowland water gauging stations. Objectively this also may be true, but we established the opinion that spatially this river flow regime can not be related to lowland river stream. There are just too many hydrogeographical differences. A closer look in the data showed us that fall in year 2000 was very wet in all of Slovenia, and has influenced the flow of Sava Dolinka in Kranjska Gora. The primary high waters in fall in period 1991-2000 are therefore very high – 2,01, and that is also the reason why statistical method put this location in different cluster. The analysis of period 1991-99 gives us distinguished lower primary maximum – 1,7 – and this period flow regime of Kranjska Gora is in the group with high mountain cluster (Frantar, 2003). After detailed analysis of the causes of cluster analysis results we see that the river flow regime in Kranjska Gora has a character of ***high mountain pluvio-nival type.***

The analysis of the river flow regimes in period 1991-2000 discovered astonishing main ascertainment: The Sava River has in the entire stream the pluvio-nival regime type with three different variants: high mountain, medium mountain and lowland.

3.3. Comparing both periods

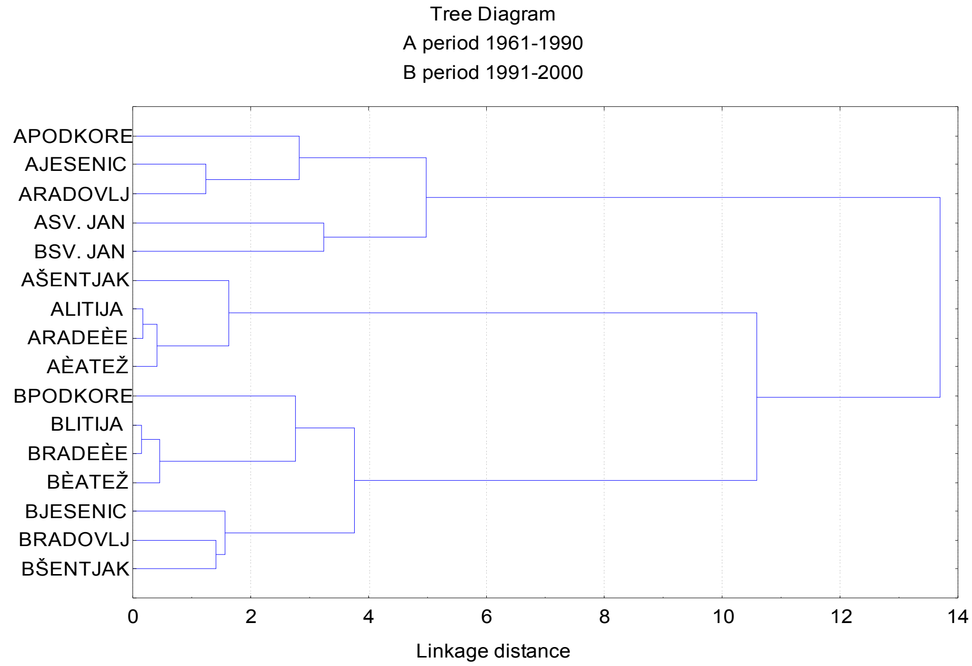


Figure 4: Tree diagram of hierarchical clustering for both periods for all water gauging stations. A-Stations for period 1961-1990, B-stations for period 1991-2000

In a »normal« climatic state we would expect that the correlation between the same stations in different periods is higher as to different stations in same period. But as already seen in individual period analysis we now are faced with changes also here. We establiched three basic groups (figure 4):

The first cluster consists of the flow regimes of locations upstream from Radovljica in period 1961-90 and with Sv. Janez in 1991-2000. The Sv. Janez flow regime is the only one that is connected to itself in different periods. This cluster (mostly high alpine stations in 1961-90 period) is more different to all other flow regimes, even to 1961-90 regimes on downstream stations. It shows that the river flow regime types with characteristics of 1961-90 period upstream from Radovljica after 1991 are gone.

Second group is formed out of river flow regimes in 1961-90 period downstream of Šentjakob. The distance to the »new era« flow regimes is closer as to reference period.

The last cluster consists of the new period river flow regimes (except Sv. Janez). All these regimes are highly connected which shows us that after year 1991 important changes in Sava's flow regimes have occurred. Despite the declining trend of average annual flows on all water gauging stations (figure 5), the flow coefficient extremes are increasing on all locations downstream from Sava Dolinka and Sava Bohinjka inflow.

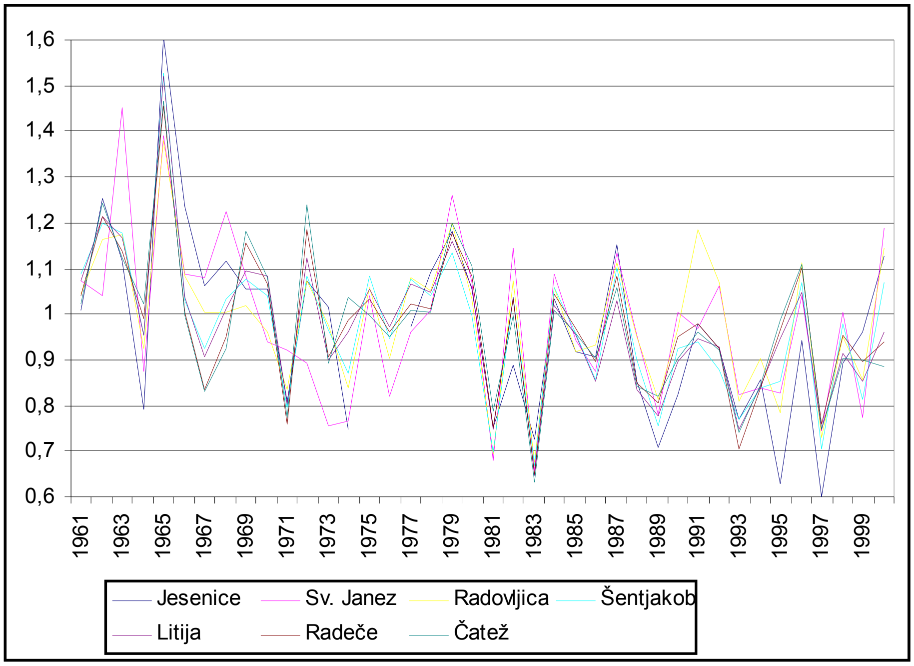
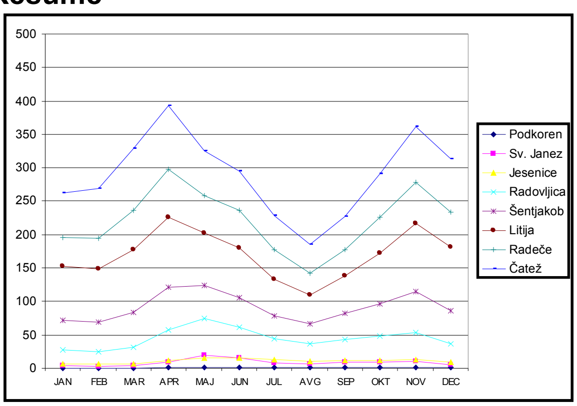


Figure 5: Coefficient of average annual flow in water gauging stations to reference average flow 1961-90 (source: ARSO, 2003b)

4. Resume



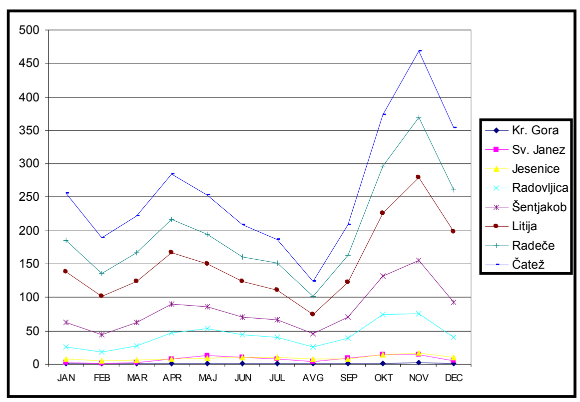


Figure 6: Average monthly flows in m^3/s for river Sava gauging stations in period 1961-1990 (left) and 1991-2000 (right) (source: ARSO, 2003b)

Flow analysis after 1961 discovered changes in river flow characteristics:

1. On all analyzed locations (figure 5) the declining trend of average annual flows is observed. We can define the cause as: less precipitation and higher evapotranspiration.
2. Increased extremes of river flow coefficients downstream from inflow of Bohinjka and Dolinka – bigger annual fluctuations – confirms assumptions of climate-change researches on bigger fluctuations.
3. Distinctive flow increase in late Fall months due to higher temperatures (less snow) and significant decrease of spring / summer flow in river. More rain as snow causes less snow retinence in the mountains and increases the fall outflow (Braun, 2002, p. 3).
4. After the year 1991 the analysis discovered new river flow regimes compared to the reference period regimes: the nivo-pluvial regime is gone mostly due to fall rain outflow increase. The result of hierarchical clustering is pluvio-nival regime type with three different variants: high mountain, medium mountain and lowland.

5. References

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