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TREND DETECTION IN HYDROLOGICAL SERIES OF MAIN LITHUANIAN RIVERS

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Abstract. Runoff being as a main element of the hydrologic cycle and resulting from the climatic processes at the same time can be as an indicator of global climate change. In reality, river runoff mostly characterized by visible extreme values – floods and draughts, therefore the hydrological time series of extreme values for trend detection where chosen.

There were selected annual maximum (spring flood), average and minimum (summer time low flow) runoff values of the main Lithuanian rivers (with lowest human impact) over the last 50 years from the major hydrologic regions. The objective of the paper is to determine the trends of selected hydrological series evaluating possible impact of climate change factors employing different statistical tests.

The results obtained indicate the substantial difference in runoff fluctuation tendencies among the investigated maximum, average and minimum runoff rates.

Keywords: runoff, hydrological time series, trend

1. Introduction

Discussions regarding global climate change has become more and more popular during recent years. Climate change processes have been observed throughout the world. Scientists presented reasoned arguments that human activities had started to increase global climate warming since the 7th decade of the past century. The rising temperatures induce extreme natural phenomena – resulting in more powerful and more frequent floods, rainstorms, hurricanes, heat disasters, floods, etc.

Currently the most common natural disaster in Europe is flooding. Consequently, even more attention has been paid to one of the hydrologic cycle's element - rivers runoff - which unquestionably depends on climate change processes [1].

It is essential to explore all available data in order to make an analysis of the hydrological parameters' variations. The Global Runoff Data Center (GRDC) closely examines these issues. A group of scientists explored 195 rivers around the world and presented the following results:

13,8 % of investigated rivers runoff increases;

15,8 % – decreases;

70 % of the changes were insignificant..

The results demonstrates the complexity of river runoff formation process [2, 3, 4, 5].

There were number of scientific studies done regarding the climate change and water resources in Northern Europe and Baltic countries. However, no definitive conclusions could have been made as the studies employed different statistical methods and inconsistent study periods.

A series of studies conducted by Lithuanian scientists on climate change impact for Lithuanian rivers runoff was selected for this study. A non-parametric Mann–Kendall test was employed to analyze their data. The annual and seasonal runoff analyses using a Mann–Kendall test revealed the prevailing fluctuations – runoff increased during winter months and, decrease during spring, while only insignificant variations were observed during summer and autumn seasons. Historical spring runoff data was examined for the periods of 1961–2003 and 1941–2003 in order to establish the general trend in runoff volume in Lithuania. However, no significant changes were detected, i.e. rivers medium runoff is stable. Similar results were registered for the period of 1922–

2003 – there were no significant trend changes registered in the major part of the territory, with exception of Southeastern Lithuania, where negative trends were observed, i.e. decrease in flooding runoff volume [6, 7]. We concentrated our attention on peak flow of spring flood, because it is very important for predicting of catastrophic events.

In order to prepare a representative statistical analyses, it is important to employ applicable methods; therefore, this article aims to determine the runoff trends for the selected hydrological series and to evaluate possible impact of climate change employing different (not only linear) statistical tests.

2. Research subject and methodology

For the purpose of this research, rivers with the following characteristics were selected: biggest rivers that are least affected by economic activities, and availability of yearly maximum, average and minimum runoff values during spring floods over the last 50 years. As a result, 16 rivers were selected: five rivers from the Southeaster part of Lithuania, five from the Midlands and six from the Western part of the main country's hydrological regions (Table 1).

Hydrological time series values are asymmetric, thus they are replaced by their relative ranks, because the hydrological time series values do not fits to normal distribution. Therefore non-parametric tests are more suitable for analysis of short time series data.

Two non-parametric tests were chosen for this research work: Mann-Kendall and Spearman-Rho.

Mann-Kendall tests whether there is a trend in the time series data. It is a non-parametric test. The n time series values (X_1, X_2, X_3, ….., X_n) are replaced by their relative ranks (R_1, R_2, R_3,….., R_n) (starting at 1 for the lowest up to n).

The test statistic S is:

$$S = \sum_{i=1}^{n-1}\left[\sum_{j=i+1}^{n} \operatorname{sgn}\left(R_j - R_i\right)\right] \quad (1)$$

where
sgn(x) = 1 for x > 0
sgn(x) = 0 for x = 0
sgn(x) = -1 for x < 0

If the null hypothesis H_o is true, then S is approximately normally distributed with:

$$\mu = 0$$
$$\sigma = n(n-1)(2n+5)/18 \quad (2)$$

The z-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables):

$$z = |S| / \sigma^{0.5} \quad (3)$$

A positive value of S indicates that there is an increasing trend and vice versa.

Spearman's Rho test is a rank-based test that determines whether the correlation between two variables is significant. In trend analysis, one variable is taken as the time itself (years) and the other as the corresponding time series data.

Like the Mann-Kendall Test, the n time series values are replaced by their ranks.

Table 1. Characteristics of the rivers basins being analysed

Hydrological regions of Lithuania	Rivers	Hydrological observation station	Basin area up to water sampling location, km^2	Lakes, %	Swamps, %	Forests, %	Sand content, %
Southeast	Merkys	Puvočiai	4300	0,9	10	46	67
	Verknė	Verbyliškės	694	2,0	14	12	20
	Ula	Zervynos	679	0,3	11	84	89
	Žeimena	Kaltanėnai	752	8,9	10	29	44
	Šventoji	Anykščiai	3600	4,7	10	12	30
Central	Lėvuo	Kupiškis	307	0,3	5	12	20
	Šušvė	Josvainiai	1100	0,1	14	21	12
	Šešupė	Kalvarija	444	2,8	15	7	8
	Dubysa	Lyduvėnai	1130	0,7	13	14	20
	Mūša	Ūstukiai	2280	0,8	3	14	1
Western	Bartuva	Skuodas	612	0,2	5	3	3
	Jūra	Tauragė	1690	0,2	6	20	8
	Minija	Kartena	1230	1,4	8	20	12
	Veiviržas	Mikužiai	358	0,1	2	18	10
	Akmena	Paakmenis	308	0,8	11	5	1
	Venta	Papilė	1570	0,6	7	27	10

The test statistic ρ_s is the correlation coefficient, which is obtained in the same way as the usual sample correlation coefficient, but using ranks:

$$\rho_s = S_{xy} \Big/ \left(S_x S_y\right)^{0.5} \quad (4)$$

where

$$S_x = \sum_{i=1}^{n} (x_i - \overline{X})^2$$

$$S_x = \sum_{i=1}^{n} (y_i - \overline{Y})^2$$

$$S_x = \sum_{i=1}^{n} (x_i - \overline{X})(y_i - \overline{Y})$$

and x_i (time), y_i (variable of interest), $\overline{X}$ and $\overline{Y}$ refer to the ranks ($\overline{X}$, $\overline{Y}$, Sx and S_y have the same value in a trend analysis).For large samples, the quantity $\rho_s \sqrt{n-1}$ is approximately normally distributed with mean of 0 and variance of 1 (critical test statistic values for various significance levels can be obtained from normal probability tables).

The general graph of standard deviations was applied, which is similar to commonly used integral graphs of integral coefficients enabling an estimate variation/fluctuations of long-term data. In total 11 tests have been performed employing the indicated program for calculations, as it is considered suitable not only for initial calculations of time series data in selecting the appropriate test, but also for evaluation of results' significance obtained from those tests.

The parameters of climate change, i.e. fluctuation/variation trends of air temperatures and amount of precipitation - were examined employing the same methods.

3. Results of research

Rivers runoff is one of the main water's circulation paths in nature and its volume depends on many natural factors.

Territory of Lithuania is divided into three main hydrologic regions which coincide with physical-geographical regionalization of the country, namely: Southeastern, Midlands and Western regions.

Due to the sandy soils rivers of Southeastern Lithuania are characterized by the most even distribution of runoff, because rapidly infiltrated melting snow-water and rainwater replenish the resources of underground water, which is gradually delivered to the rivers during the low water seasons. Underground water supply amounts to 60 % of the total yearly runoff. A great number of lakes situated in the Southeastern part of Lithuania have considerable influence sustaining the even distribution of runoff as well.

Rivers of Midland of Lithuania are low-flow and distribution of runoff is very uneven during the year. That is because of quite low soil permeability or even the waterproof of the soils and low flows of the rivers, with low underground water supply. Western part of Lithuania includes Pajūris Lowland and Žemaičiai Highland. The runoff of rivers is very complex because of frequent thaws and variable snow cover during winter periods plus intensive spring and autumn rainstorms.

Based on the integral graphs long-term monitoring data were analyzed in order to evaluate runoff fluctuation trends and to determine cyclic variations (Fig. 2).

Integral graphs were produced for the rivers included in the current research for the period 1956 to 2005, which demonstrated that all rivers were low-flow during 1960 to 1995 with the exception of Šušvė above Josvainiai, Merkys above Puvočiai, Šventoji above Anykščiai and Ūla above Zervynos.

The latter four rivers were described as low flow till year 2005 while other rivers received enough water not to be classified as low-flow indicating that last decade had more precipitation.

The average annual runoff data were selected as a starting point for the analysis of statistical hydrological parameters of the rivers selected for the research. Interpretation of the calculations produced by TREND program indicated that only sequences of hydrological data of rivers Žeimena and Šventoji in the Southeastern part of Lithuania were statistically significant, i.e. statistics of tests exceeded the calculated critical values which mean an increase in the fluctuation trend. Out of investigated rivers in Lithuanian Midlands none of them had statistically significant hydrological sequence. According to the results obtained for Western part of Lithuanian rivers, using Mann-Kendall test the only statistically significant upward trend was observed in Akmena River above Paakmeniai, while Spearmen's-Rho test also indicated Bartuva river above Skuodas.

Having analyzed maximal spring runoff rates, the results demonstrated that: both Southeastern and Midlands Lithuanian rivers' runoffs decreased during the last 50 years, although the decrease in Šešupė river above Kalvarija and Dubysa river above Lyduvėnai was statistically insignificant. Statistical analysis of Western Lithuania's rivers revealed that only Venta river above Papilė had a statistically significant decrease in runoff, while runoff changes for other rivers were statistically insignificant (Table 2).

The analysis of minimal spring runoff values determined that increase in rivers' runoff trend was statistically significant in all Southeastern hydrological region rivers, except Ūla river above Zervynos, which test statistics did not exceed the calculated critical values.

Statistically significant increase in upward fluctuation trends were observed in Midlands of Lithuania, including Šešupė above Kalvarija, Dubysa above Lyduvėnai and Mūša above Ūstukiai.

2 Fig. Cumulative deviations long-term monitoring data

Table 2. Statistical results of minimum, maximum and medium runoff tests of the investigated rivers

Rivers, Hydrological observation station	Minimum runoff					Maximum runoff					Average runoff				
	Test statistic	Critical values			Result	Test statistic	Critical values			Result	Test statistic	Critical values			Result
		a=0.1	a=0.05	a=0.01			a=0.1	a=0.05	a=0.01			a=0.1	a=0.05	a=0.01	
Mann-Kendall test															
Merkys- Puvočiai	2.06	1.62	1.99	2.51	S (0.05)	-2.37	1.7	1.97	2.37	S (0.05)	0.78	1.68	2.02	2.72	NS
Verknė- Verbyliškės	2.52	1.75	2.07	2.69	S (0.05)	-1.77	1.7	1.99	2.74	S (0.1)	0.41	1.71	1.94	2.49	NS
Ula- Zervynos	0.03	1.58	1.9	2.58	NS	-2.93	1.64	1.89	2.45	S (0.01)	-0.93	1.71	2.04	2.62	NS
Žeimena- Kaltanėnai	3.61	1.53	1.84	2.63	S (0.01)	-1.10	1.63	2.02	2.79	NS	2.34	1.64	1.97	2.64	S (0.05)
Šventoji- Anykščiai	3.15	1.66	1.99	2.53	S (0.01)	-2.23	1.6	1.99	2.64	S (0.05)	1.84	1.59	1.88	2.33	S (0.1)
Lėvuo- Kupiškis	1.00	1.64	1.96	2.50	NS	-3.77	1.71	1.97	2.57	S (0.01)	0.56	1.71	2.01	2.64	NS
Šušvė- Josvainiai	-1.67	1.72	2.00	2.78	NS	-2.22	1.62	1.99	2.46	S (0.05)	-0.98	1.63	1.97	2.49	NS
Šešupė- Kalvarija	2.57	1.66	2.01	2.73	S (0.05)	-1.47	1.61	1.91	2.44	NS	0.33	1.75	2.07	2.59	NS
Dubysa- Lyduvėnai	2.35	1.65	1.92	2.60	S (0.05)	-.032	1.78	1.98	2.36	NS	1.02	1.66	1.98	2.42	NS
Mūša- Ūstukiai	2.21	1.61	1.93	2.65	S (0.05)	-2.52	1.58	1.93	2.43	S (0.01)	0.79	1.56	1.86	2.59	NS
Bartuva- Skuodas	2.65	1.62	2.02	2.60	S (0.01)	-1.28	1.65	1.99	2.72	NS	1.16	1.65	1.93	2.57	NS
Jūra- Tauragė	3.84	1.76	2.06	2.63	S (0.01)	-0.18	1.61	1.93	2.64	NS	0.88	1.71	2.04	2.57	NS
Minija- Kartena	1.02	1.56	1.91	2.59	NS	-0.58	1.67	2.07	2.69	NS	1.06	1.61	1.99	2.64	NS
Veiviržas- Mikužiai	1.96	1.66	1.89	2.58	S (0.05)	0.53	1.63	2	2.52	NS	0.69	1.66	1.95	2.44	NS
Akmena- Paakmenis	1.65	1.61	1.91	2.60	S (0.1)	-1.02	1.71	2.07	2.48	NS	2.28	1.59	1.92	2.58	S (0.05)
Venta- Papilė	1.49	1.55	1.86	2.50	NS	-3.4	1.6	1.92	2.58	S (0.01)	0.74	1.69	2.03	2.61	NS
Spearman's Rho test															
Merkys- Puvočiai	2.10	1.66	2.02	2.64	S (0.05)	-2.48	1.65	1.88	2.53	S (0.05)	0.63	1.71	2.02	2.48	NS
Verknė- Verbyliškės	2.62	1.61	1.93	2.63	S (0.05)	-1.95	1.66	2.02	2.69	S (0.1)	0.48	1.71	2.13	2.63	NS
Ula- Zervynos	0.12	1.71	2.02	2.60	NS	-2.91	1.71	2.05	2.73	S (0.01)	-0.87	1.74	2.10	2.70	NS
Žeimena- Kaltanėnai	3.51	1.64	1.95	2.62	S (0.01)	-1.19	1.63	1.94	2.60	NS	2.25	1.68	1.95	2.58	S (0.05)
Šventoji- Anykščiai	2.95	1.68	2.06	2.73	S (0.01)	-2.26	1.62	1.97	2.64	S (0.05)	1.87	1.61	1.98	2.50	S (0.1)
Lėvuo- Kupiškis	0.92	1.66	2.00	2.65	NS	-3.66	1.65	1.94	2.67	S (0.01)	0.81	1.74	2.02	2.64	NS
Šušvė- Josvainiai	-1.50	1.75	2.06	2.73	NS	-2.50	1.64	1.93	2.45	S (0.01)	-0.83	1.62	1.90	2.60	NS
Šešupė- Kalvarija	2.35	1.70	2.00	2.50	S (0.05)	-1.49	1.70	2.04	2.57	NS	0.18	1.73	2.01	2.56	NS
Dubysa- Lyduvėnai	2.46	1.65	1.89	2.36	S (0.01)	-0.16	1.68	1.99	2.57	NS	1.21	1.73	2.03	2.60	NS
Mūša- Ūstukiai	1.75	1.67	1.88	2.58	S (0.1)	-2.37	1.69	2.04	2.65	S (0.05)	1.07	1.64	1.96	2.62	NS
Bartuva- Skuodas	2.77	1.74	2.01	2.44	S (0.01)	-1.11	1.65	1.94	2.51	NS	1.77	1.68	1.93	2.49	S (0.1)
Jūra- Tauragė	3.76	1.68	2.01	2.61	S ()0.01	-0.31	1.72	2.09	2.72	NS	1.20	1.69	1.97	2.59	NS
Minija- Kartena	1.37	1.58	1.89	2.57	NS	-0.62	1.61	1.89	2.42	NS	1.40	1.70	2.04	2.66	NS
Veiviržas- Mikužiai	2.45	1.83	2.12	2.81	S (0.05)	0.32	1.69	2.09	2.64	NS	1.11	1.73	1.99	2.72	NS
Akmena- Paakmenis	1.88	1.65	1.91	2.55	S (0.1)	-1.15	1.70	1.98	2.82	NS	2.53	1.71	1.99	2.58	S (0.05)
Venta- Papilė	1.60	1.62	2.01	2.56	NS	-3.36	1.72	2.01	2.48	S (0.01)	0.95	1.63	2.03	2.59	NS

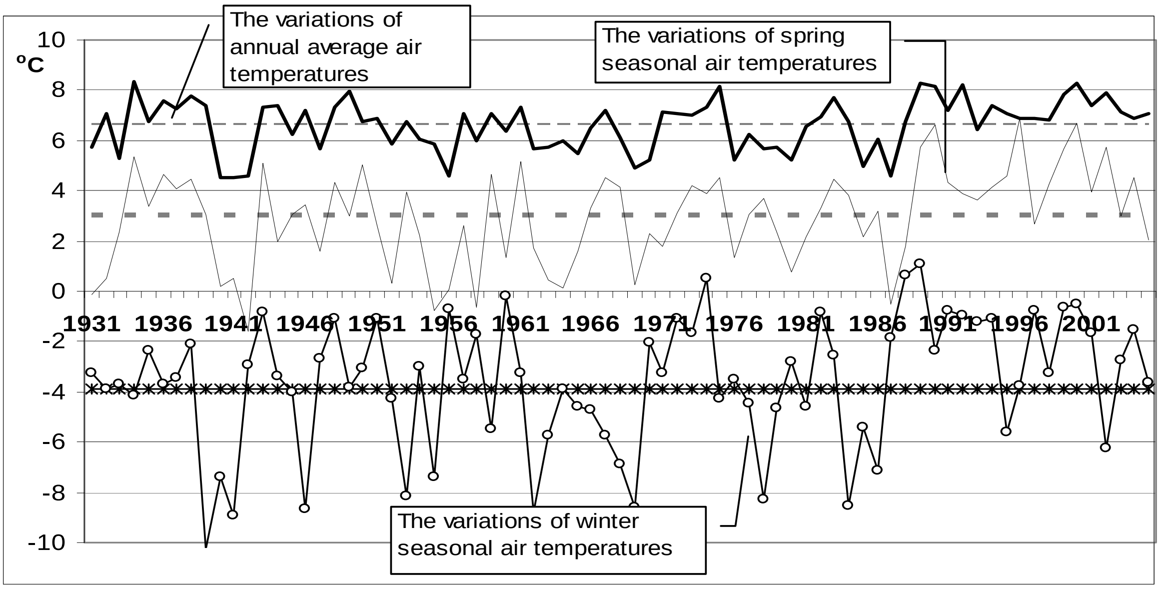

Fig. 3. The variations of annual average of winter, spring seasonal air temperatures at Kaunas MS

Only statistically insignificant increases of rivers runoff have been observed in Minija above Kartena and Venta above Papilė in the Western hydrological region of Lithuania. In summary, the research results demonstrated that the average annual river runoffs in the majority of the studied rivers increased, spring maximum runoffs decreased, while annual minimal runoffs increased. After examining general fluctuation of runoff rates, the following two questions that have to be explored, namely: what determines river runoff fluctuations and are they a result of global climate change or is it a simple natural cycles?

Analysis of seasonal temperatures in Lithuania determined that average annual temperature as well as spring and winter average seasonal temperatures increased during the last few decades. The most important finding was that seasonal temperature differential was steadily decreasing. The differences in annual average winter and summer air temperatures are shown in Figure 3.

In that in the last 20 years the annual air temperature increased from 6,6 to 7,4 degrees centigrade. The increase of temperature during the spring season was even more obvious – from 3,0 to 4,6^{o}C. An increase in precipitation amount, both the annual mean and seasonal values, has been determined, especially in winter season. During the other seasons increase in precipitation amount was not statistically significant. However due to the increased winter air temperature, precipitation is not retained on the ground in the form of snow and ice till the beginning of springtime, when the major spring floods are expected to happen (Fig. 4).

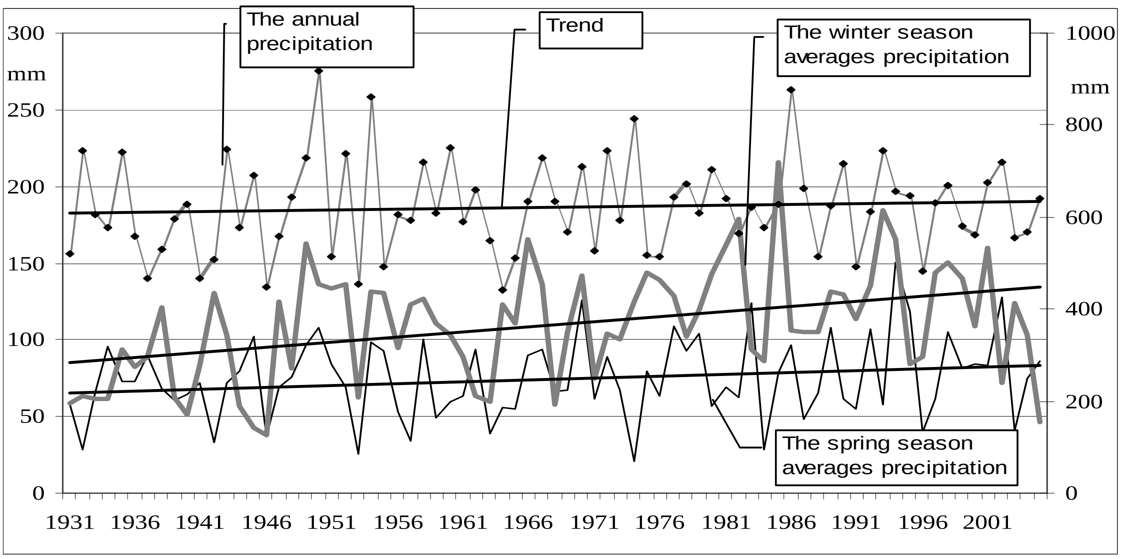

Fig. 4. The variation and trends of annual averages, winter and spring season averages of precipitation at Kaunas MS

In order to test the latter hypothesis, the annual distribution of the runoff rates of investigated rivers were analyzed using the TREND program. Rivers with statistically significant trend ratios were determined in different hydrological regions: Merkys river above Puvočiai and Ūla river above Zervynos in Southeastern part of Lithuania, Mūša river above Ustukiai in Midlands and Venta river above Papilė in Western part of Lithuania.

The annual distribution of runoff rates of the past decades are displayed in Figure 5.

The analysis of the results indicates two peaks of the annual runoff during the last decades, i.e. the maximum values registered in spring, especially during April, and a bit lower values in autumn – during October or November. Averaged values of monthly peak flow for different periods indicates evident redistribution of runoff in time.

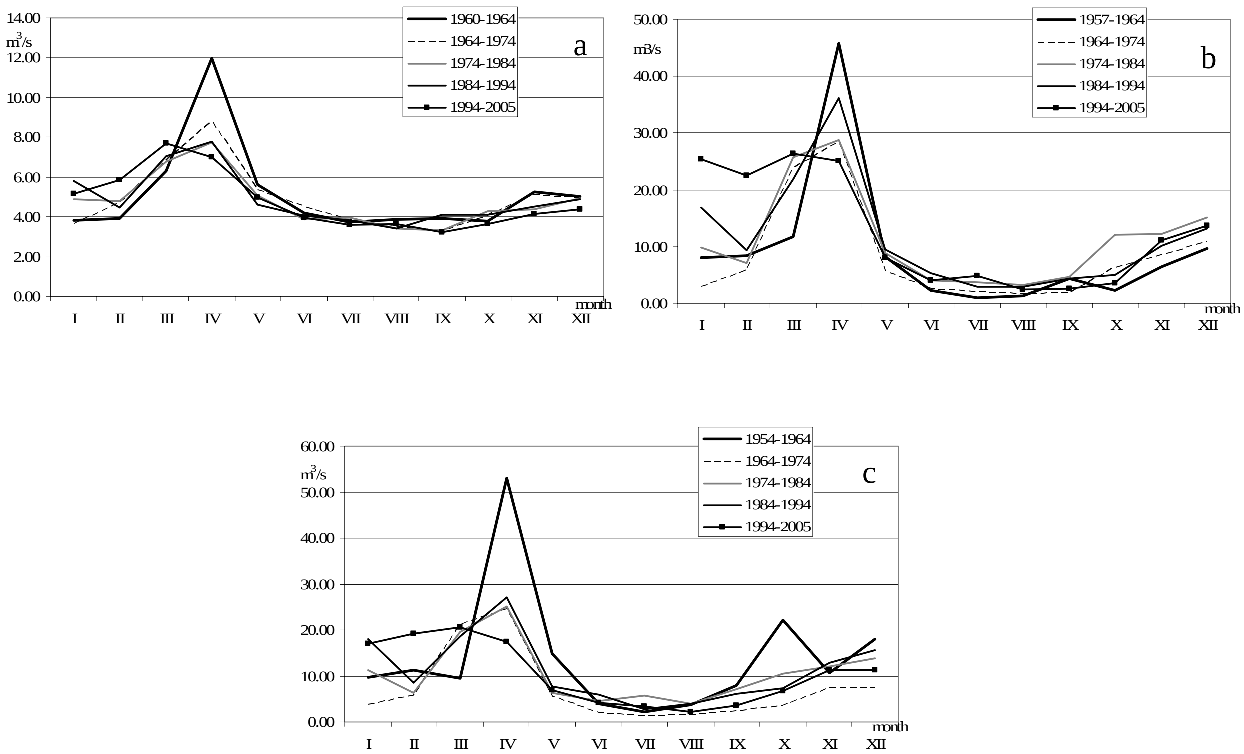

Fig. 5. The averages of monthly peak flows during different periods of Merkys, Ūla, Mūša and Venta

The volume of spring flow 30-40 years before was concentrated in snowmelt period and resulted one-piece hydrograph. In last decades we have more uniformly distributed flow for all winter season with few peaks.

Since 1964 the maximum spring runoffs decreased 1,5 – 2 times with peak spring flows occurring in March and April, and autumn runoff peak flows occur in October and November. However, since 1994 in all studied rivers, runoff was relatively steady without obvious peaks.. Spring flooding was distributed during 3 months – February, March and April. Statistically insignificant runoff fluctuations observed during summer and autumn seasons, especially in Southeastern part of the country, while the same trend of averaged flow has been observed during October, November and December in Midlands and Western part of Lithuania.

4. Conclusions

Non-parametric statistic methods were employed for testing trends of hydrological series of fluctuations of runoffs', because the hydrological series values violate a normal probability distribution. Using both Mann-Kendall and Spearmen tests, statistical analysis of all 16 rivers studied detected 11 positive statistically significant trends while analyzing minimal annual runoffs. They were 3 (or 4 events using a rank-based Spearmen's test) positive statistically significant trends for average mean runoffs, and 8 negative trends for maximal spring runoffs.

Generally, fluctuation of runoff can be related to climate change. The precipitation volume increased over the studied period, especially in the winter season.. Redistribution of rivers' flow has been detected with runoff becoming steadier without obvious peaks. Spring flood is normally distributed over a three-month period – February, March and April. Statistically insignificant runoff fluctuations were observed during summer and autumn seasons, especially in the Southeastern part of the country. Whilst the Midlands and Western parts of Lithuania autumn increased runoff has been observed during October, November and December.

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