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THE INFLUENCE OF LITHOLOGICAL STRUCTURE ON RIVER RUNOFF IN THE SOUTH-EASTERN LITHUANIAN HYDROLOGIC AREA

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Abstract. Due to the recently increasing frequency of extreme changes in river runoff regime, scientific literature deals with the characteristics of runoff formation. Works are carried out in analyzing climate changes and a lot of attention falls on land-use structures. Following thorough analysis of the lithological structure of river basins in South-eastern Lithuanian hydrologic area in separate costal zones, this article aims at evaluating river runoff formation characteristics. The basin lithological factor was calculated based on Quaternary map of Lithuania M 1 : 50000 and Lithuanian river map M 1 : 50000 using ArcGis software. In order to carry out more thorough analysis of the influence of lithology in given territories, sections of 0-20 m, 50-200 m, 200-500 m, 500-800 m, 800-1000 m and >1000 m were established, calculating the distance in meters from the riverbank. River basins of typical lithological structure (sandy, loamy, argillaceous) were selected and examined. The period of the year 1960-2007 was analyzed as this period saw the greatest amount of precipitation (up to 33% probability) and relation between the flow and precipitation was established as well as that with the lithological structure, established following the derivation of a hydromodule. Research has shown that basin areas, separate parts or sections of basins containing over 50% sand have an inversely proportional influence on the river runoff. Larger (more than 7 km^2) homogenous argillaceous areas have double impact on the runoff: direct one during the period of 11.78 – 55.17% probability of precipitation and inversely proportional one during the period of 69.63 – 98.55% probability of precipitation. In cases of river basins, parts or sections of basins with loam percentage lower than 70%, precipitation and runoff correlation characteristics are similar to those of sandy basins, whereas in case of loam percentage higher than 70%, precipitation and runoff correlation resembles that of argillaceous basins.

Keywords: lithology, river runoff, precipitation, basin.

1. Introduction

The distribution of river runoff throughout the year is determined by climatic and bedrock surface factors. Climate influences the overall wateriness during the year and runoff regime phase periods. Bedrock surface factors (the size of a river basin, its lithological composition, and forest area in the river basin) might cause fundamental changes to the runoff regime formed by climatic factors (Gailiušis et al.; 2001; Uhlenbrook et al.; 2001).

Recently, cases of ill-timed floods throughout the world have come to the news more and more frequently. It has been estimated that the amount and intensity of precipitation has grown 10 percents during the second half of the 20th century (Pfister et al.; 2004).

In the context of global climate change, Lithuanian climatologists have not yet recorded fundamental changes in multi-annual precipitation patterns but have established its clear seasonal distribution, i.e. winter season precipitation has increased significantly while that of summer season has seen a significant decrease (Galvonaitė and Valiukas, 2005; Bukantis et al.; 2001; Bukantis and Rimkus, 2005).

A number of researchers engage in the analysis of runoff formation conditions, particularly while analyzing the impact of land-use structures on river runoff (Jones and Grant, 1996; Ashagrie et al.; 2006). H. Pauliukevičius (2006) looked into the impact of land-use on small river basins runoff. The research has demonstrated slight and moderate inverse correlation of average annual runoff module with forest area and direct correlation with arable land area in small river basins with varied land-use in the end of a low-wateriness period and the beginning of a higher wateriness period.

However, the number of scientific research focusing on the aspects of runoff formation in terms of lithological structure of a river basin is scarce; moreover, the existing ones deal with it in terms of water quality since infiltration characteristics of lithological structures determine the quality of both runoff and water (Kevin et al.; 2000; Alan, 2004).

Following thorough analysis of the lithological structure of river basins in South-eastern Lithuanian hydrologic area, this article aims at evaluating river runoff formation characteristics.

2. Methods

South-eastern Lithuanian basins of typical lithological structure were selected: sandy ones including Ula (Zervynos water measurement station), Zeimena (Kaltanenai-Pabrade); argillaceous ones including Verkne (Verbyliskes); loamy ones including Sventoji (Anyksciai-Ukmerge), Streva (Semeliskes-Strevininkai) (Fig 1). The lithological factor of the basins was calculated based on Quaternary map of Lithuania M 1 : 50000 and Lithuanian river map M 1 : 50000 using ArcGis software. Four classes were identified according to soil composition: 1 sand, 2 loam-sandy loam (further on referred to as loam), 3 clay and 4 peat, with relative infiltration indices ascribed to them for the purpose of further analysis. Lithological analysis of selected parts of river basins was carried out and, where it was possible and long-term water measurement station data was available, the "clearest" territories in terms of analysis were identified. In order to carry out more thorough analysis of the influence of lithology in given territories, sections of 0-20 m, 50-200 m, 200-500 m, 500-800 m, 800-1000 m and >1000 m were identified, calculating the distance in meters from the riverbank. Each section's lithological structure was established (Table 1). Lithuanian Hydrometeorological Service data of flow and meteorological conditions (precipitation) in the year 1960 – 2007 was used. The years that saw the greatest amount of precipitation (up to 33% probability) were analyzed and relation between the flow and precipitation was established as well as that with the lithological structure, established following a derivation of a hydromodule.

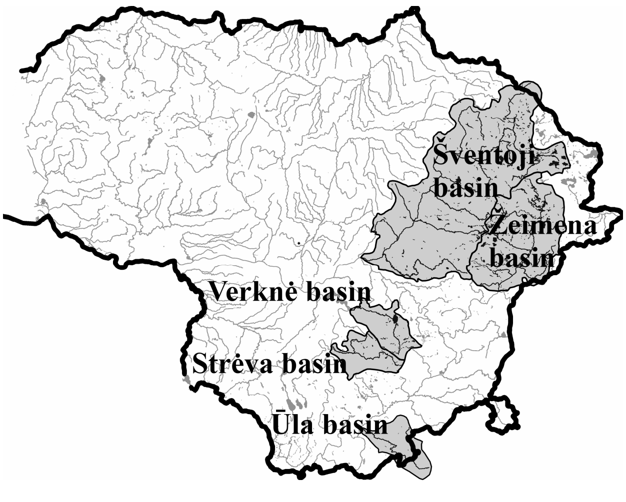

Fig 1. Analyzed river basins within the territory of Lithuania

3. Results and discussion

The calculation the percentage of sections' area in the analyzed basins revealed that more than 60% of the basin territory is covered by sections of 50-200 m and 200-500 m along all rivers except for Zeimena and Verkne (sections of 50-200 m, 200-500 m and 500-800 m respectively) and Ula where sections of 50-800 m cover approximately 40% of the basin territory, the section of >1000 m covers over 35% of territory. This distribution of section areas is directly influenced by the density of hydrographic net (Jablonskis et. al.; 2007). This structure was considered in further calculations.

Ula basin is covered by sand in 72.3%, of the overall 453.1 km^2 of basin area within its Lithuanian territory, 15.3% is covered by loam, 0.8% is covered by clay and 11.8% is covered by swamps and peatbogs. Loam takes the northern part of the middle reaches stretching in large sections of an average of 4 km^2, while clay is found in the southern part of the middle reaches (Fig 2). The percentage of sand, moving further from the riverbank, changes gradually from 52% to 80% of the section area, while the change of the percentage of loam is 10-15% in the sections of 0-200 m and >1000 m and 21-19% in the sections of 500-1000 m. Clay is found only in the section of >1000m in the percentage of 2.1%. The analyzed area of 379 km^2 (Zervynos water measurement station) covers the upper and middle reaches of river Ula, located in the territory of Lithuania. In this territory, the percentage of sand makes 68.3% of the basin area and changes gradually from 46.8% to 75.6% across sections. Loam, covering 17.8% of basin area, makes 20.2-20.8% in the section of 500-1000 m and 11.2-16.5% in other sections. Clay is found in the southern part of the middle reaches, in the section of >1000 m where it takes 2.6% of the section area. Swamps and peatbogs stretch in the upper reaches and the middle reaches, in the percentage of 38.4-29.9% in the littoral (sections of 0-200 m) and 11.8-6.5% in further sections.

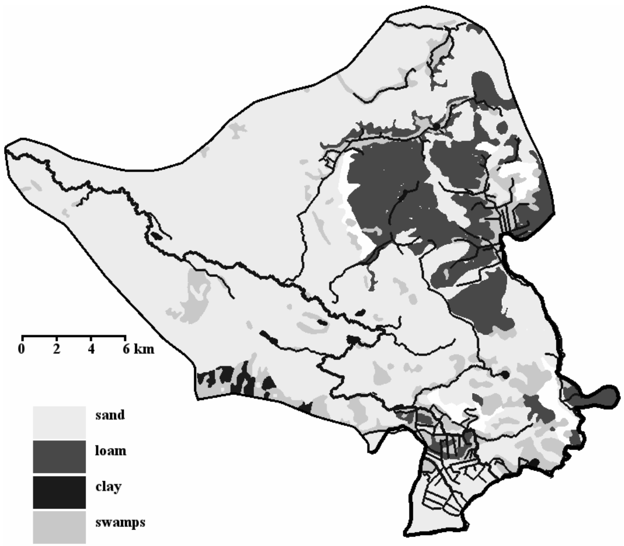

Fig 2. Lithological map of Ula river basin

Table 1. Lithological Structure of the Analyzed Rivers

Lithological group	River, Measurement station	Section	Lithological structure, %			
			sand	loam	clay	swamps
Sandy	Ula, Zervynos	All	68.3	17.8	0.9	13.3
		0–50 m	46.8	11.2	0.0	38.4
		50–200 m	53.6	16.5	0.0	29.9
		200–500 m	66.0	22.2	0.0	11.8
		500–800 m	71.9	20.2	0.0	7.7
		800–1000 m	71.6	20.8	0.0	7.5
		over 1000 m	75.6	15.2	2.6	6.5
	Zeimena, Kaltanenai–Pabrade	All	57.1	22.2	0.7	13.7
		0–50 m	28.8	9.2	0.5	17.3
		50–200 m	54.1	23.0	1.2	21.7
		200–500 m	61.1	27.1	0.7	11.1
		500–800 m	64.2	26.0	0.4	9.4
		800–1000 m	66.3	22.4	0.7	10.3
		over 1000 m	66.1	20.7	0.7	12.4
Argillaceous	Verkne, Verbyliskes	All	43.8	35.3	11.8	1.1
		0–50 m	28.9	25.6	12.1	15.6
		50–200 m	35.8	35.8	16.5	11.8
		200–500 m	40.4	38.2	16.4	4.9
		500–800 m	49.2	36.3	9.7	4.6
		800–1000 m	55.5	34.0	5.6	4.8
		over 1000 m	59.9	34.7	0.9	4.5
Loam–sandy loam	Sventoji, Anyksciai-Ukmerge	All	27,9	60,4	1,2	7,7
		0–50 m	28,2	35,7	0,6	15,2
		50–200 m	31,5	56,0	0,6	11,8
		200–500 m	27,6	66,5	1,1	4,8
		500–800 m	25,8	68,0	2,1	4,0
		800–1000 m	26,6	68,5	1,1	3,7
		over 1000 m	20,8	73,8	3,0	3,0
	Streva, Semeliskes-Strevininkai	All	45,6	36,7	0,7	10,9
		0–50 m	18,3	15,8	0,3	19,4
		50–200 m	33,4	39,8	1,0	25,5
		200–500 m	52,2	39,4	1,4	6,9
		500–800 m	55,4	39,4	1,0	4,1
		800–1000 m	55,7	41,1	0,0	3,0
		over 1000 m	56,1	40,9	0,0	3,0

55.8% of the overall Zeimena basin area of 2792.7 km^2 is covered by sand, 24.2% is covered by loam and 0.7% is covered by clay. According to a number of authors, areas with 7% of territory covered by lakes and 12.4% covered by swamps and peatbogs influence equal distribution of wateriness. Lithological structures are equally distributed across the basin, only areas of loam and clay may be considered more significant in four territories in the upper and lower reaches. Swamps and peat are distributed in the sections of 0-200 m (16-20%) with the approximate percentage of 9% in further sections. Areas of sand that cover as few as 28% in the section of 0-50 m, increase significantly up to 54% in the section of 200-500 m and continue increasing gradually, reaching 65% in the section of >1000 m. Loam covers 9% on the banks (section of 0-50 m) and largest areas, making 29%, are found in the sections of 200-800 m. The analyzed territory is located between Kaltanenai and Pabrade run-off measurement stations; it includes the area of 1828 km^2 covering Zeimena middle reaches with a larger area of sand covering 57,1% of territory, reaching over 64% in the sections of 800->1000 m. The percentage of loam is smaller (26.0-27.1% in the section of 500-800 m) with small amounts of clay. The percentage of lakes is not different from the overall percentage in the basin, namely, 7%; swamps and peatbogs make approximately 19% in the littoral (in the sections of 0-200 m) and approximately 10% in further sections (Fig 3).

Clay covers 13.3% of the overall Verkne basin area of 727.5 km^2, most of it located in the lower reaches with a few holdings of the size of 0.2-0.3 km^2 located in the middle reaches. Loam areas are distributed equally throughout and make 34.5% of the basin area, varying from 35% to 37% in separate sections. The amount of sand, which makes 43.4% of the basin area, increases gradually from 31% to 59%. Swamps (7% of the basin) are mostly located in 0-200 m littoral areas with the percentage of 11-15%. The examined area of 694 km^2 is distinctive for its relatively low sandiness (28.9-40.4% in the sections of 0-500 m) and loam structures (25.6-38.2% in the sections of 0-500 m) as well as seemingly low percentage of clay, namely, 11.8% of the basin in the sections of 0-500 m with 93% of it located in one large holding in the lower reaches of the river.

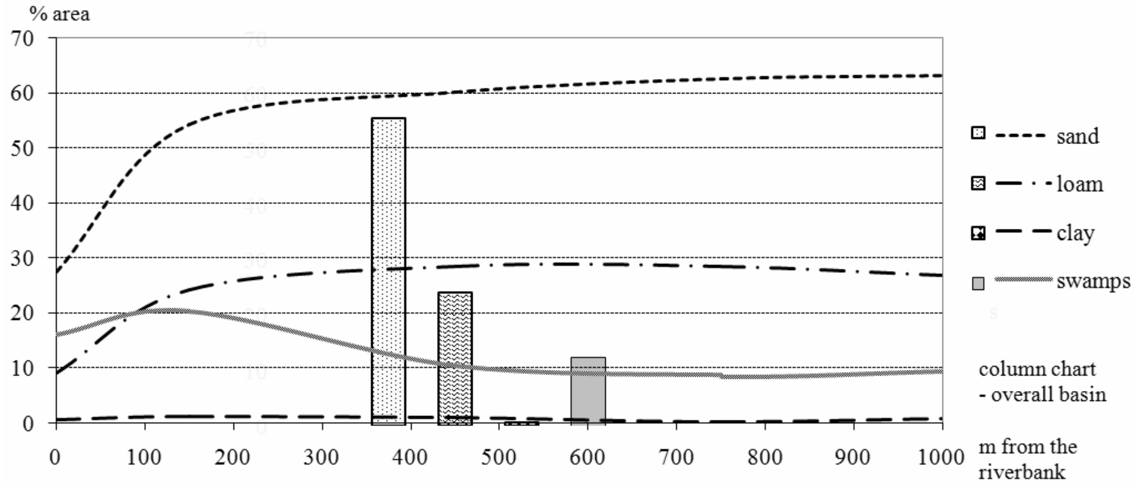

Fig 3. Change of lithological formations of the river Žeimena, distance from the bank

55.5% of Sventoji basin area of 6888.8 km^2 is covered by loam. On the riverside, in the areas of 0-200 m, it covers 31.2-51.6% of area, in the section of >1000 m is makes 57.2% and the biggest area (62.5-63.7%) is covered in the sections of 200-1000 m. Sand that covers 31.9% of basin area is distributed more equally, making approximately 30% in each section. Clay covers 0.8% of basin area and is found in equal percentage (0.7-1.2%) in each section. The analyzed basin territory of 1840 km^2 (Anyksciai - Ukmerge) was selected due to higher percentage of loam (60.4%) and lower percentage of sand (27.9%). Areas of loam gradually increase in the sections of 0-500 m from 35.7-66.5% and from 68.0-73.8% in further sections of 500-1000 m. Sand that makes approximately 30% of the area of sections of 0-500 m further on gradually decreases down to 20.8%.

The second loamy basin selected was the 758.9 km^2 Streva basin, 41.1% of which is covered in loam structures, distributed equally across the whole area of the basin along the river. The distribution in sections of 50-500 m and >1000 m is similar, with the percentage of 39.3-43.1% and in the section of 500-1000 m it is respectively 48.6% and 53.5% of section area. Although sand covers a similar basin area (38.8%) but it is mainly concentrated in two holdings: 55 km^2 in the lower reaches and 96 km^2 in laky and boggy upper reaches. The analyzed territory of 434 km^2 (Semeliskes-Strevininkai) is in 62.8% area covered by equally distributed loam. 18.2% of sand, which makes up to 15.6% in the sections of 0-800 m and 22.6-24.6% in further sections. 9% of clay is concentrated in several holdings of approximately 2-3 km^2 below Elektrėnai pond, which, together with a number of smaller ponds, largely determines the flow (Fig 4).

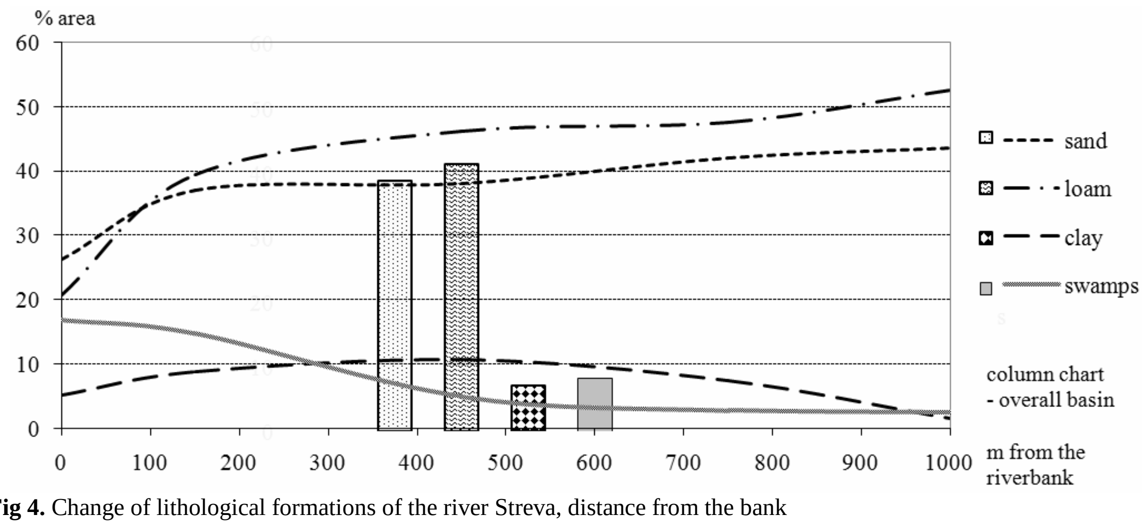

Fig 4. Change of lithological formations of the river Streva, distance from the bank

Following the identification of the year that saw large amounts of precipitation (up to 33% probability), flows of respective years were chosen and expressed in a hydromodule. Research showed that precipitation does not have direct influence on river runoff. Evaporation naturally plays an important role but lithological structure of river basin determines the flow of precipitation to surface-water and its evaporation from the surface of the basin.

The analysis of rivers with sand making approximately 55% of their basins showed that in case of average annual level of precipitation of 1.45% probability, the probability of Ula river runoff reaches 30,37% and that of Zeimena reaches 51,03% (Fig 5).

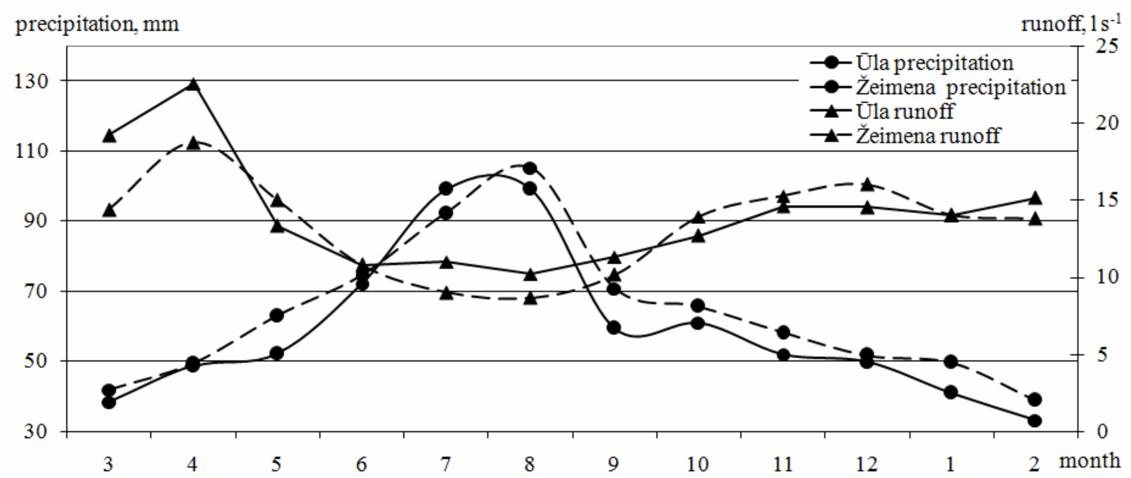

Fig 5. Distribution of runoff and precipitation in maximum precipitation years in the group of rivers with sandy lithology

This variation in runoff distribution was determined by other lithological structure elements and, most importantly, their distribution in separate sections. The greatest influence in Ula and Zeimena river basins was caused by swamp areas taking 13.3% and 13.7% of the overall basin area respectively and, as it is widely known, swamps are a good water reservoir. The analysis of the influence of the amount of precipitation on runoff in separate seasons led to a conclusion that in case of maximum precipitation (1.45% probability) in river Ula, the river runoff in spring was 44.83%, in summer it was 20.04% and in autumn it was 34.50% probability. Since the river basin contains large number of swamps and almost no clay areas (they make 0.9% of the basin, and all are located in the furthest section, in the south of the middle reaches), precipitation has no significant influence on the river runoff. The situation in river Zeimena is rather different. Here, in case of high level of precipitation, the river runoff probability in spring was 30.37%, in summer it was 32.44% and in autumn it was 51.03%. The river, similarly to Ula, contains large sandy areas and a rather significant swamp area (13.7% of the basin), moreover, Zeimena basin includes approximately 0.7% clay areas located in four holdings in which, during wet periods with high amount of precipitation, fine-grained lithological structures may prevent infiltration; thus water reaches the river channel by surface runoff and increases river flow.

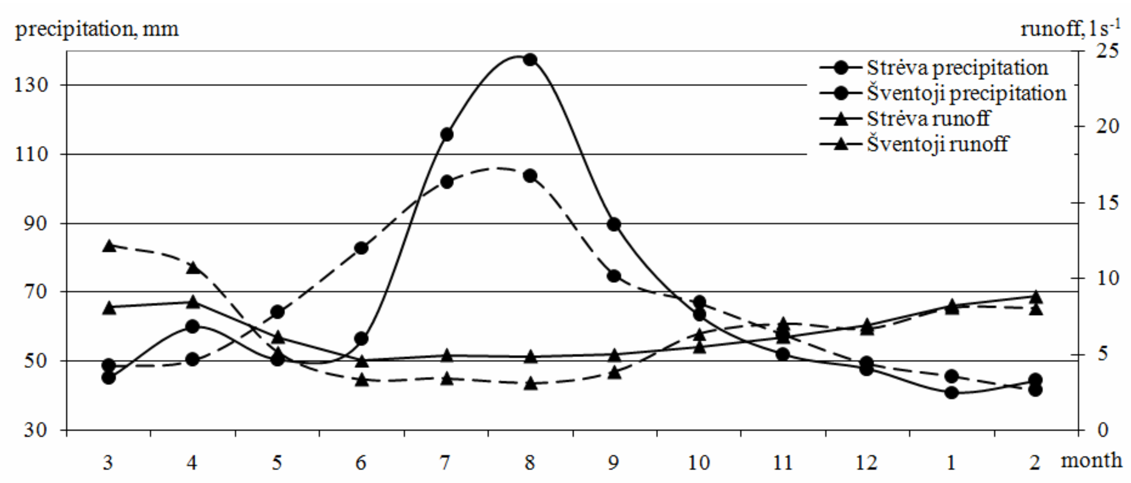

Fig 6. Distribution of runoff and precipitation in maximum precipitation years in the group of rivers with loamy lithology

While analyzing rivers of loam group it was noticed that in case of medium annual level of precipitation of 1.45% of probability, which constitutes maximum levels of precipitation in the analyzed period, river flows corresponded to 9.71% of probability in Streva and 13.84% in Šventoji. Seasonal analysis showed that in case of maximum precipitation Streva river flows corresponded to 42.77% in spring, 61.36% in summer and 7.64% in autumn. The situation in river Sventoji is similar but the flow probabilities established showed that the runoff is lower than in river Streva. In case of maximum precipitation, flow probability varied from 15.91% in spring to 65.50% in summer and 5.58% in autumn. In the basins of both rivers bogs and lakes take similar basin areas but higher amounts of loam has greater influence on seasonal runoff, which is revealed in the analysis of the change of Sventoji river runoff throughout the year. In river Streva, below Elektrėnai pond, solid clay areas are present that, during rainy season, influence daily flow in case of torrential precipitation (Fig 6).

The analysis of the change of runoff in river Verkne suggested that in case of maximum precipitation the river runoff was 11.78% of probability. Seasonal analysis showed that in spring the runoff probability in Verkne was 38.64%. In summer the runoff was 24.17% and in autumn it was 17.98% of probability. In Verkne basin the correlation of precipitation and runoff is reduced by the presence of swamp areas making over 7% and those of loam making up to 35% of the basin. It has been established that solid areas of clay during the wet season have influence only on the change of daily runoff of torrential precipitation, while during dry seasons inverse correlation is observed.

4. Conclusions

In the analyzed basins of rivers attributed to the group of rivers with sandy lithology (over 55% of sand), sand areas in the sections increase moving to the direction opposite the river bank from 28.8% to 75.6% of section area; loam areas are the largest in the sections of 200-800 m (20.2-36.3%); clay areas are distributed unequally. Sand areas of over 50% in the basins, separate parts of basins or sections have inversely proportionate influence on river runoff.

It has been established that homogenous argillaceous areas of 2-4 km^2 have double impact on the runoff: direct in periods with precipitation probability of 11.78-55.17% and inversely proportionate in period with precipitation probability of 69.63-98.55%.

In river basins of the loamy group of rivers, loam areas make up to 73.8% of the basin area with largest loam areas registered in the sections of 500 m and further. With loam percentage in a river basin, part or section of a basin lower than 70%, the characteristics of correlation of precipitation and runoff resemble those of sandy river basins and in case of those with loam percentage higher than 70%, the relation between precipitation and runoff resembles that of argillaceous basins.

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