Flood risk assessment in the Nemunas River delta area of Lithuania: a case study

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Abstract

The main Lithuanian river Nemunas with the length of 937 km drains the area of 98.100 sq. kilometres. Its mean runoff is about 6.6 l/s/km². The River Nemunas drains the NW part of the North Belarusian Plain as well as it collects water from a hilly and lake including Lithuanian plain. Then it falls into the Curonian (Kuršių marios) Lagoon, which is a transit basin on the way to the Baltic Sea. The area climatic conditions depend on the solar radiation and the circulation of the atmospheric air masses moving from the West to the East mostly. The climate conditions are soft continental. The difference between the temperatures of the coldest and the warmest months is about 24°C. Winter period is usual with ice cover onto the river surface. The level of precipitation is about 850 mm per year, 30% of which go into the rivers. In previous decades about 40% of the river water runoff usually was observed during spring flood (March-April). During warm winters frequent winter water floods occur and sometimes their runoff in comparison with the spring one doesn't differ very much in their readings. Recently autumn or even summer flood events became more frequent too. The mean water runoff of the River Nemunas near Smalininkai is 540 m³/s (fluctuates between 150 and 6820 m³/s). The River Nemunas level-gauge observations in Smalininkai (situated 112 km up the river from the mouth) take their beginning in 1811. The most important and dangerous phenomenon in the lower part of the river is occurrence of rather frequent flood events, especially those taking place since the last decades of the 19th century, which appear as a result of the narrowing of the river bed for the navigational purposes. Then a number of dams were constructed on both the banks of the river.

The intention of this presentation is analyzing the long-term river-level observations in Smalininkai and trying to find the relationship between the fluctuations of the mentioned parameter and the readings of flood water level with the possible prediction of the situation in the various residential and agricultural areas situated lower than the investigated level-gauge post. The other important relationship is between the ice cover break-up events and the level-gauge readings especially of those which occur in winter and spring. It is very important to mention that during recent decades the major changes in the river hydrological regime take place as a result of significant changes in climate conditions. During the extreme spring flood the water level can reach even 8 meters high with the sequent flooding of the living areas and agricultural fields in lowlands.

All the mentioned description of the situation resulted to the idea of the appliance of the complex system of long-term investigations in Smalininkai to the flood risk prediction in the River Nemunas Delta that stretches in the area of approximately 2200 sq. kilometres.

1. Introduction

The drainage area of the most important and significant water route - River Nemunas occupies the area of 98 100 km². The length of the river is 937 km. The Nemunas River with quite high runoff (6.6 l/s/km²) drains the North-Western part of the North Belarusian Plain and the Lithuanian more hilly and lake-bearing plain (Fig. 1). The climate of the area belongs mostly from the sun radiation and circulation of the atmospheric weather masses from the West to the East. The climate is soft continental. The differences between warmest and coldest months range within 22-23°C. The level of the precipitation is about 850 mm per year and about 30% of it gets to the rivers. About 40% of the river water flows during spring flood occurring mostly during March and April. During warm winters frequently took part winter water flood and it sometimes draw nearer to spring flood one. The many years discharge of the river Nemunas near Smalininkai is 540 m³/s and fluctuates from minimum runoff values of 92 m³/s in winter time (December 23, 1953) and 151 m³/s (July 21, 1964) to maximum ones as 6822 m³/s that occurred during spring time (April 12, 1829) (Dubra J., 1993).

During XX century the constantly increasing navigation in many areas no promoted to the formation of the stabile ice cover. For the first it takes part sea ports and navigable areas. The ice cover is breaking by tugboat, blowing up or thawing of the ices are hastening for the strewing of the peat and salt mixture during sunny days try to diminish consequence of the spring water fluid in the delta of the River Nemunas and not infrequently in the Curonian (Kuršių Marios) Lagoon. The Nemunas River receives water mostly from the precipitation and during snow thawing. The impact of the ground water is more considerable during dry summer and significantly weaker during the other seasons. The lowest water level is forms in the cold and prolonged winters. The goal of this work is to analyze the long time ice cover observations in Smalininkai and try to find the relationship between the fluctuations of the weather temperature and the observations of the ice cover in the Curonian Lagoon. These relationships are of primary importance when investigating the flood events in the Nemunas Delta area, because the duration of stable shore ice and last ice plays a great role in the significant water level rise process thus having a sequent extremely negative impact to the dwelling areas of several thousand people. The other important fact is the ice regime in the Curonian Lagoon which accordingly to its hydrological regime is the continuation of the Delta area of the River Nemunas.

2. Investigations

This presentation is based on the systematical investigations of the water level, flowing of the river water, ice regime that were started in the level gauge post of Smalininkai (112 km from the river mouth) in 1812 (Kolupaila, 1930; Hydrological Annals, 1945-1990). It's very difficult to find post with ice cover observations without any anthropogenic activity. Some omissions take part only during World War II (1943-1946). The long-term meteorological observations were available since 1777 in Vilnius, since 1848 - in Kaliningrad and since 1881 - in Klaipeda. The observations of the ice cover were started in Curonian Lagoon only from the beginning of this century with the some gaps during periods of the war (Seina & Palasuo, 1993). The River Nemunas partly not avoided of the anthropogenic influence. In 1959 the 16 meters-high dam of the Kaunas hydroelectric power station was put into action about 100 kilometres higher Smalininkai. The operational impact of that dam often results to the surge wave which is the 1-2 meters high at the start point and gradually diminishing on the move down. Three decades have passed since 1976 when the other dam at Vileika (Belarusian Republic) was erected in the upper reaches of Neris, the major tributary of the River Nemunas (Fig. 1). The dam is about 500 km up the river from Smalininkai and its sequent influence on the ice regime near Smalininkai is very weak.

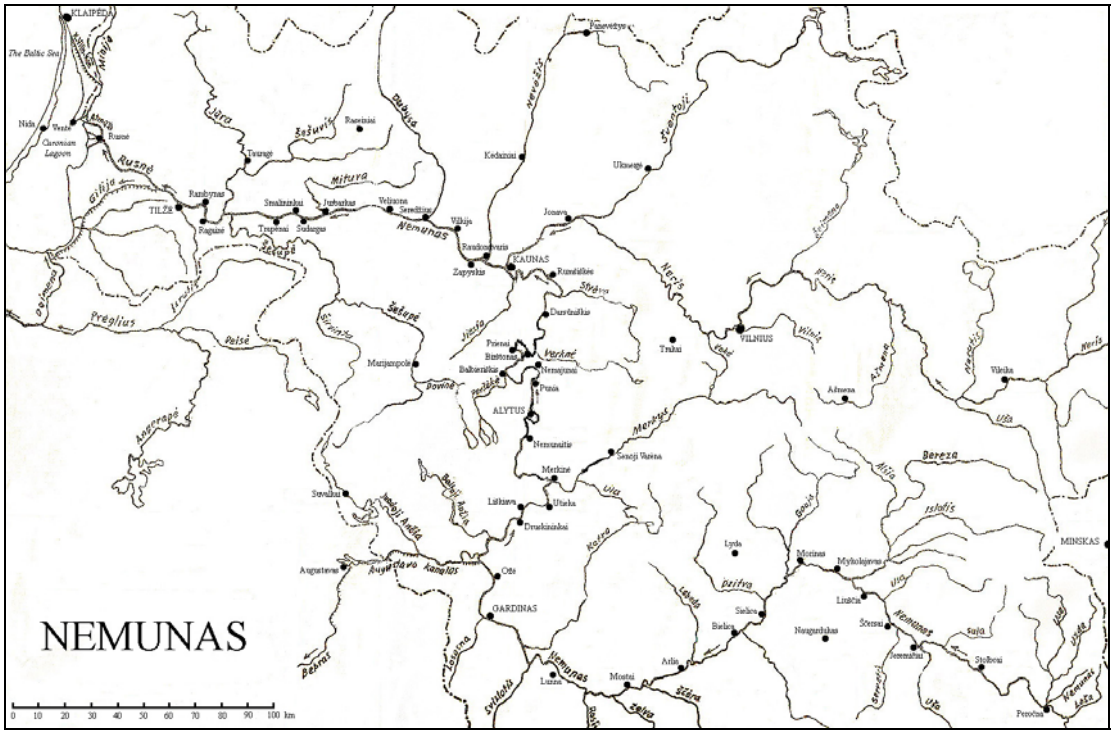

FIGURE 1. Scheme of the River Nemunas basin

3. Discussion

The aim of this paper is based on several hydrometeorological factors having the primary importance for the water level rise. Those are terms of main ice phases and the average air temperatures of the month and the sequent runoff figures.

Ice Stage	First ice	Stable shore ice	Cracked ice	Last ice	Number of ice days	Number of ice cover days
Medium (day.month)	30.11	18.12	21.03	26.03	87	108
The earliest (day.month)	30.10	08.11	22.12	03.01	134	151
Year of the earliest	1875, 1881	1919	1924	1989	1830	1909
The latest (day.month)	10.02	-	-	28.04	0	9
Year of the latest	1975	1975	1975	1839	1975	1975

TABLE 1. The stages of the ice cover in Smalininkai during last 1811/12-2005/06

Fast decrease of air temperature to the negative values results to the significant ice forming in the water bodies. The ice regime depends thoroughly on the duration of low air temperature and the intensity of these dynamic processes. The first ice in the River Nemunas near Smalininkai usually appears in the last days of November. Usually ice is formed in the beginning of December but in 1875 and 1881 it has appeared during the last days of October. During winter of 1974/75 the first ice appeared only on February 10 and then it was thawed after 10 days. During this entire winter only drifting forms of ice were observed. After 2-3 weeks since the first ice appear a stable ice cover is formed. During the third decade of March a breaking ice cover is observed thus resulting to the parallel phase of high flood water. The latest ice was noticed in the end of April. The most prolonged ice period occurred from 20 of November 1838 to the 28 of April in 1839 and respectively the shortest period that lasted 9 days took part in 1974/1975. Only during prolonged winters ice cover lasts till the end of April. During the last thirty years a tendency of weakening of the ice processes thus resulting to the significantly dropped ice duration is observed (Table 1). The recent decades show significant decrease of number of ice days and especially the stable shore ice days by 1.5 to 2 times. Some aspects are raised by the introduction of the Hydropower Plant of Kaunas, thus influencing the ice regime down the river. The presence of plant and some long-term riverine processes resulted to the slightly reduced parameters of hydrometric curve at Smalininkai (Fig. 2). It must be mentioned that water reservoir on the mentioned plant can hold the volume of the river runoff of 1% probability for 1.5 to 2 days only. From the other hand this can be possibly explained by the global warming processes consequently working on local scale.

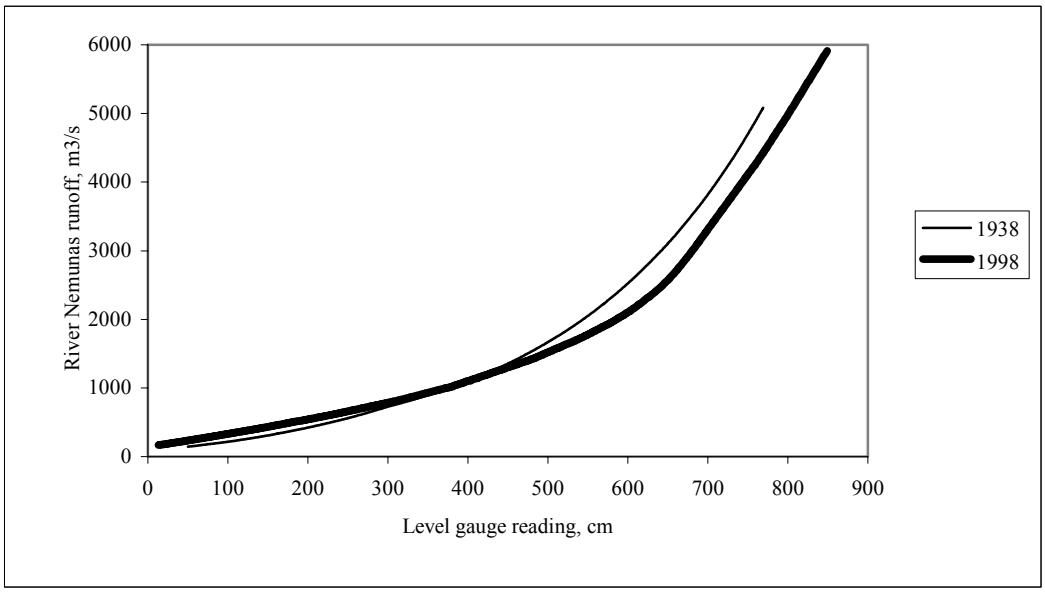

FIGURE 2. Variations of hydrometric curve in Smalininkai in 1938 and 1998

During spring flood the water level can reach ever 8 meter high. The lowest water level forms during cold and prolonged winters. We noticed that the duration of ice days in Smalininkai has good relationship to the mean winter air temperature in Vilnius (Fig. 3). Data from Vilnius was chosen because of the longest period of observations.

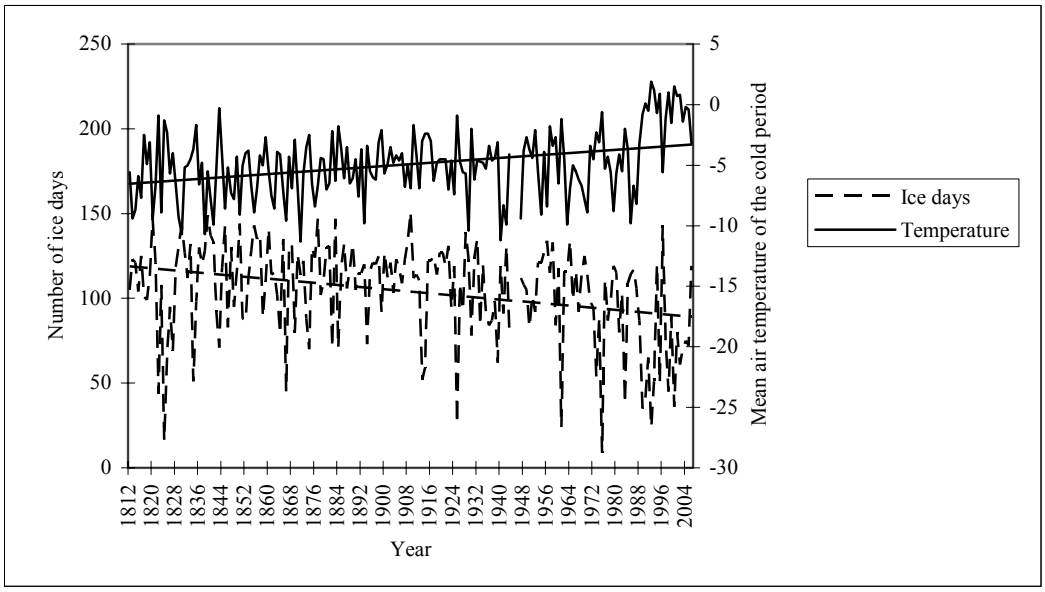

FIGURE 3. Long-term variations and trends of the mean winter air temperature and the number of ice days in the River Nemunas

The comparison of the ice regime in Smalininkai to the observations in the lagoon at the head post at Nida showed the similar annual tendencies and the same average terms of the main phases of the ice characteristic during the period of the last 200 years (Figs. 4, 5). The average number of ice days is decreasing slightly faster while the mean air temperature of the winter season is increasing (Fig, 8).

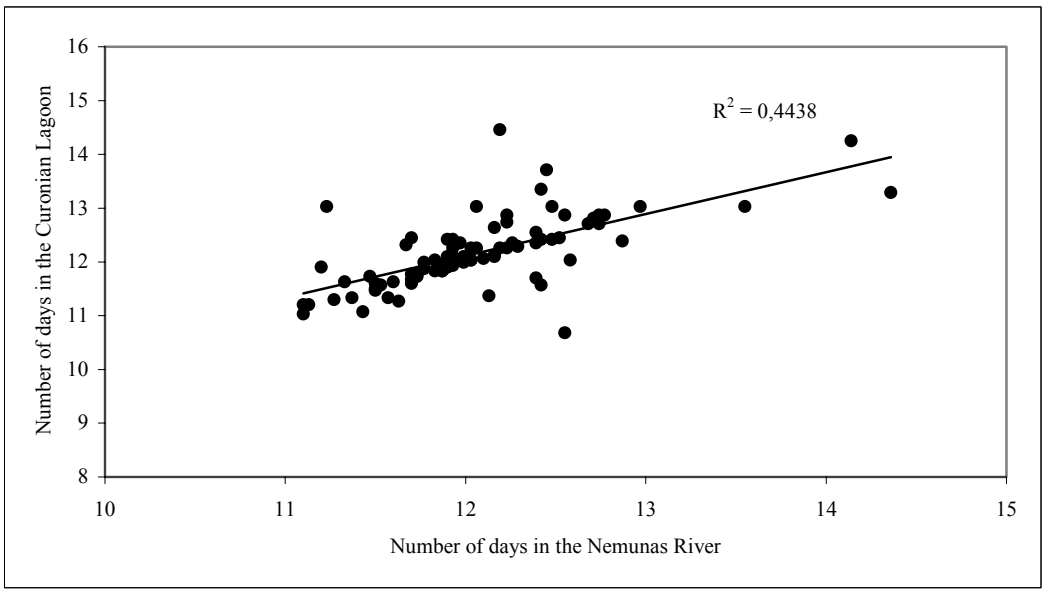

FIGURE 4. Relationship between the duration of the formation of new ice in the Curonian Lagoon and that in the Nemunas River near Smalininkai

The waters of the River Nemunas first get to the Curonian Lagoon then taking the direction to the Baltic Sea. The Curonian Lagoon is a fresh water body that is formed of the water entering from the Nemunas River but the northern part of it is marked with the intrusions of the salty marine water because of the storm surge activities. Some of authors regard the Curonian Lagoon to be the continuation of the

Nemunas River delta (Basalykas, 1958). The ice regime of the Curonian Lagoon looks similar to that of the investigated river near Smalininkai (Figs. 4, 5), except that for the duration of the stable ice shore (Fig. 6). The differences of the last case in both the water bodies occur because of the differences in the runoff regime.

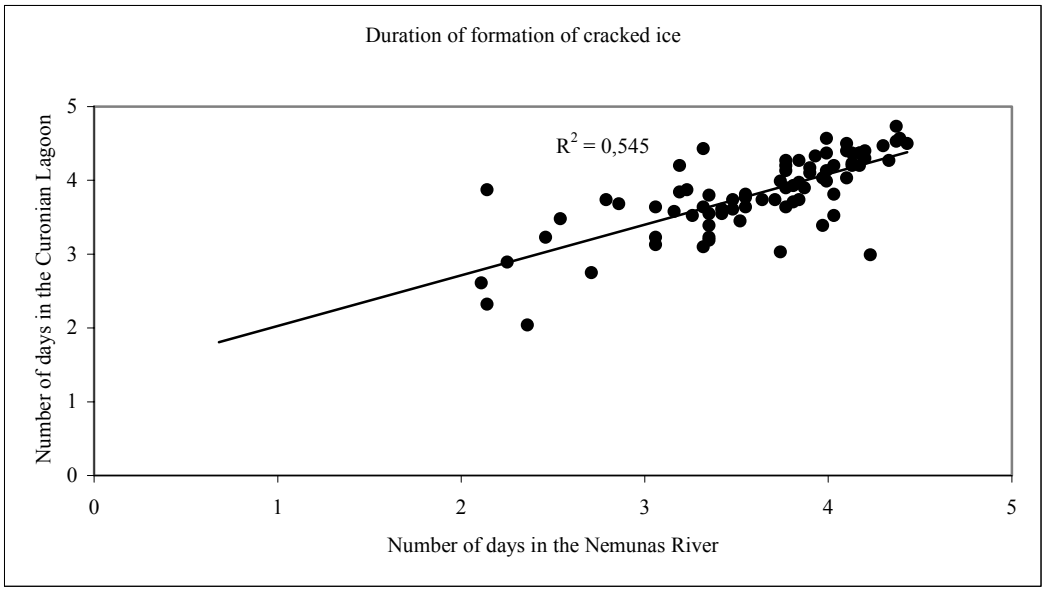

FIGURE 5. Relationship between the duration of the formation of cracked ice in the Curonian Lagoon and that in the Nemunas River near Smalininkai

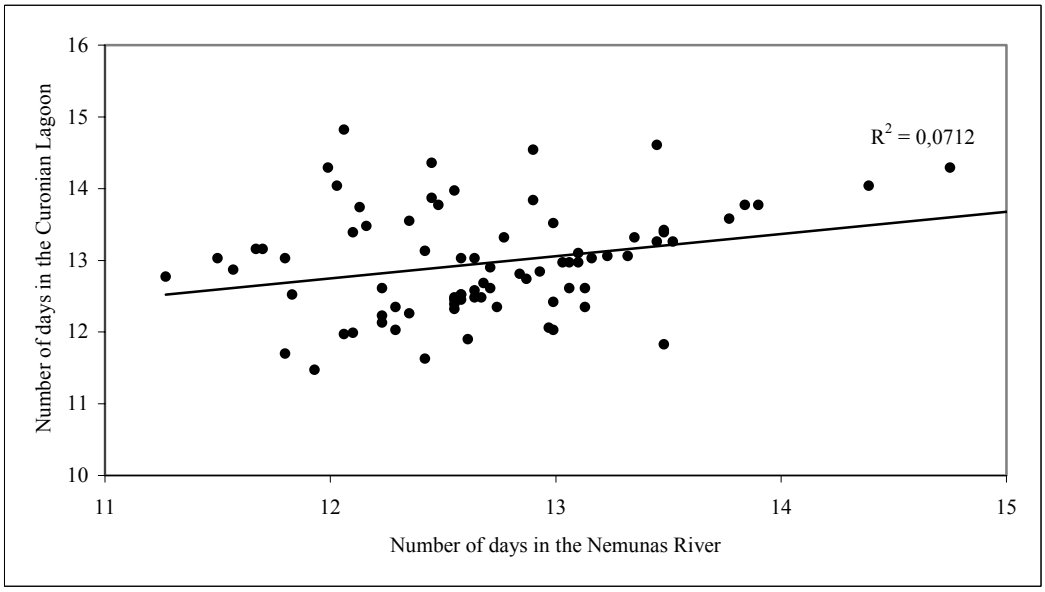

FIGURE 6. Relationship between the duration of the stable shore ice in the Curonian Lagoon and that in the Nemunas River near Smalininkai

The significant difference can be noticed during several years when advection of the cold played a significant role in near the sea coast area and even further from it. But in most the cases we have the same tendencies of the variations of the ice regime phases. Then it let to apply the long-term observation data from Smalininkai for the ice regime in Curonian Lagoon. Analysis of the ice regime data represented by the decade principle shows the significant decrease of the duration of ice days and especially of the presence of stable ice shore, which lasts by 2 time shorter than in the beginning of the 20th century (Fig. 7). Drastic changes in the ice regime take their beginning since the eighties of the last century. That's because of the occurrence of the period of mild and mostly the relatively warm winter periods. The probable duration of such a trend could be an object of the long discussion.

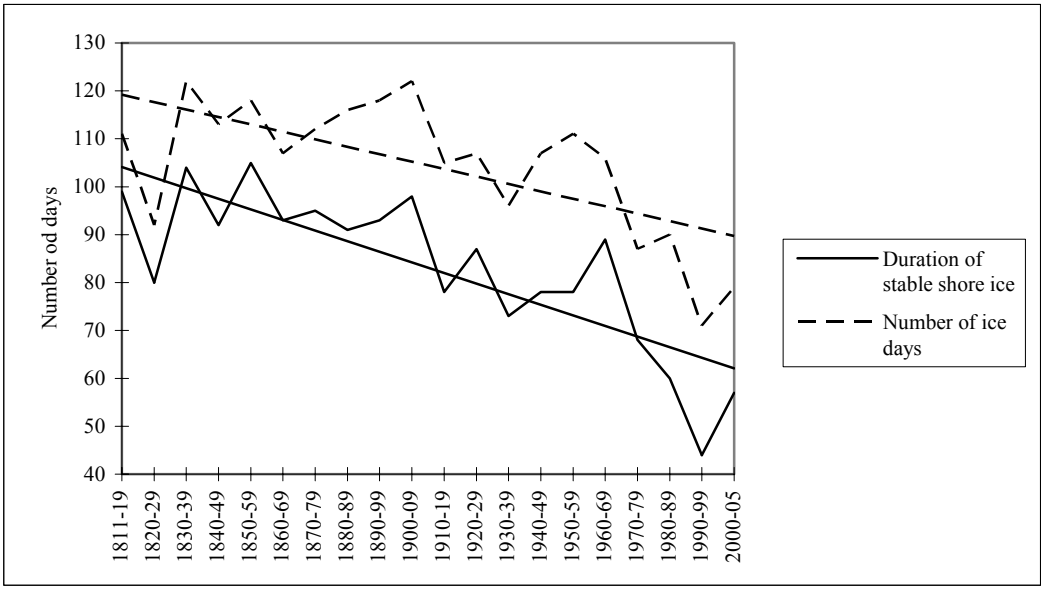

FIGURE 7. Long-term trends of the duration of the significant ice phases in the Nemunas River near Smalininkai

The average duration of ice cover ranges within the period of 3 months but during some years that could be characterized of extreme meteorological parameters this period can be prolonged to the period of 5 months or even not to be formed. The ice period during very cold winter of 1838/39 lasted for 160 days but during very soft winter of 1974/75 the duration was only 11 days. The average thickness of the ice is about 40 cm but during cold winter it can reach 60 and even more centimetres. The thickness of the ice is higher (80 cm) and water level fluctuations are more significant but the current speed in the Curonian Lagoon is lower than in the River Nemunas.

After the relatively cold period that lasted during the previous century the ice regime and weather conditions have became even milder in the course of the recent decades especially (Fig. 3). All this shows the tendencies of climate warming in our region as well. After extremely very cold period of 1939-1947 we had only warm or mild winters mostly. The latest cold winter occurred in 1986/87 only. The tendencies of the climatic regime in the River Nemunas Basin are similar to those in neighbouring countries.

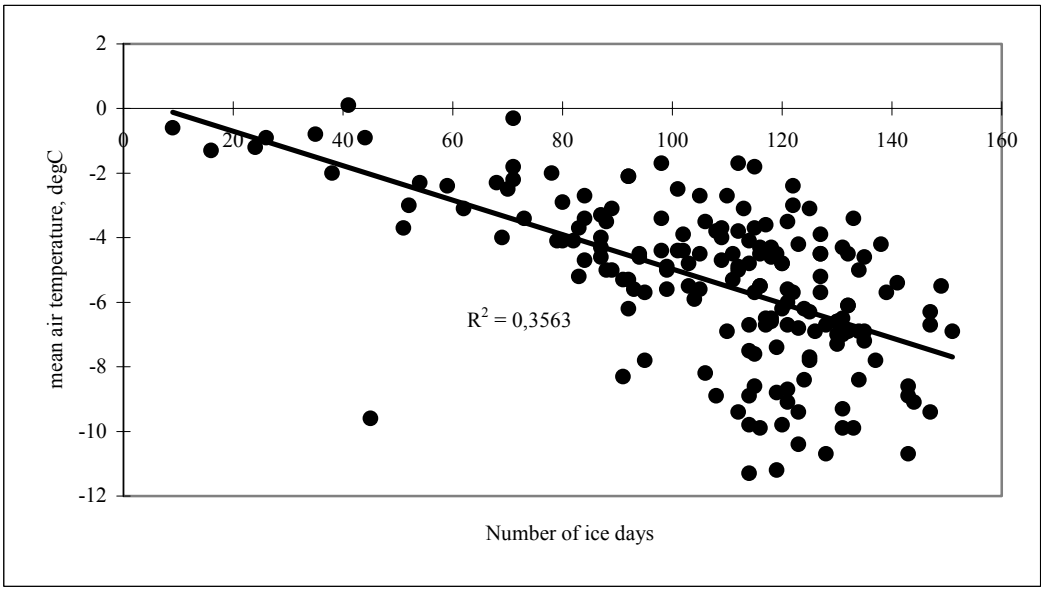

FIGURE 8. Relationship between the mean winter air temperature and the number of ice days in the Nemunas River near Smalininkai

During the last three decades (Fig. 7) the ice cover that formed in the River Nemunas was stable only for 2 months in average if to compare to those figures of the first half of the last century that were 3-3, 5 months long. The similar situation is concerning the ice presence duration in the river. This period has shortened from 4 to 3 or even 2.5 months.

The other important relationship based on long-term data was observed between the mean winter air temperature and the number of ice days in the Nemunas River near Smalininkai (Fig. 8). This relationship pays tribute when assessing the impact of the basically measured parameters of the air on the runoff volume. Long-term trends of the mean annual runoff of the River Nemunas are shown in Fig. 9.

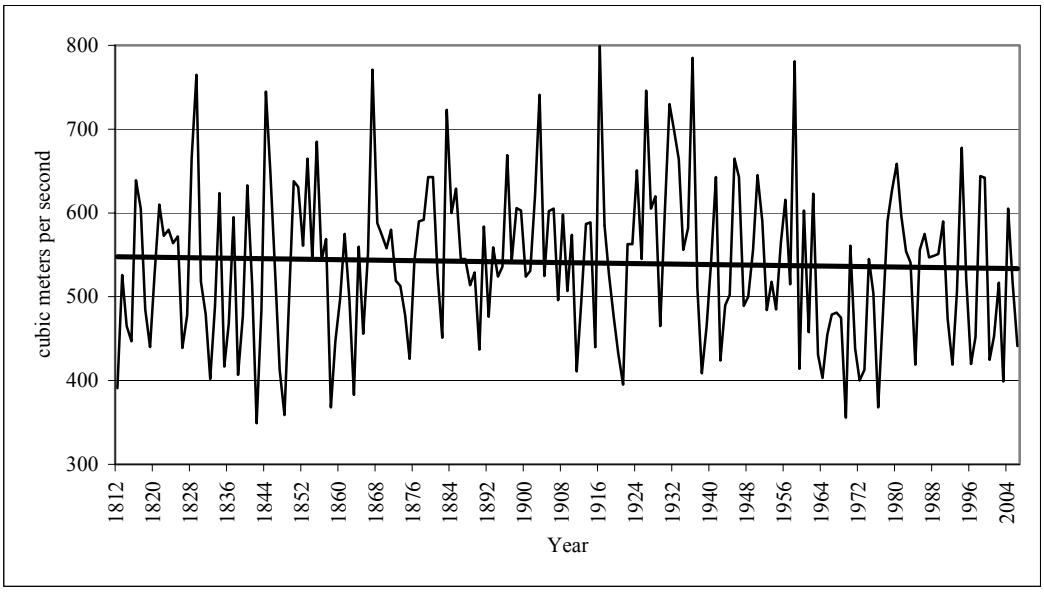

FIGURE 9. Long-term trends of the mean annual runoff of the River Nemunas

A simple linear regression model was applied in order to prove the long-term trends of the mean monthly runoff figures (Table 2).

Month	Intercept	Slope
January	417,86	+0,4736
February	420,08	+0,6063
March	666,54	+0,9732
April	1408,30	-1,3119
May	666,47	-0,5114
June	424,90	-0,2642
July	401,40	-0,3993
August	420,74	-0,4960
September	378,34	-0,1749
October	401,74	-0,0208
November	466,79	+0,1234
December	494,35	-0,0530
Year	547,84	-0,0737

TABLE 2. Simple linear regression parameters for long-term runoff trends of the River Nemunas near Smalininkai

The most significant changes occurred during spring period. A drastic reduces of runoff with the consequent disappearance of frequent flood events is observed during April and May. The trends look so that the major water volume flows down the river during February and March especially. All this can be explained that recently flood events have become of late winter to early spring character in comparison to that they occurred during the very middle of spring earlier. The other important fact is the occurrence of positive trends during the cold period from November to January. This fact could be explained by the total disappearance of relatively cold winters when a stable shore ice cover is formed. Recently we

registered the summer floods occurred because of heavy rains during July, 2007 and August, 2005. These facts still have no statistical importance in order to change the existing long-term trends, but their importance for the future is an object of serious discussion. It must be mentioned that global "greenhouse effect" plays a great role in such variations occurring on the local scale.

4. Conclusions

The ice regime in the River Nemunas near Smalininkai have the same annual tendencies and approximately the same average terms of the main ice phases forming as in the Curonian Lagoon near Nida. Only in the mouth part of the River Nemunas the duration of the ice days is longer by about half a month. These relationships can be of primary importance when assessing the possible high water appearance with consequent increase of the other hydrometric parameters. During the last three decades the ice cover that formed in the River Nemunas was stable only for 2 months in average if to compare to those figures of the last century that were 3-3,5 months. The similar situation is concerning the ice presence duration in the river. This period has shortened from 4 to 3 or even 2.5 months, thus affecting the terms of flood. The long-term ice regime analysis shows the remarkable tendencies that are possible because of some climate warming impact.

A very important statistical fact is that flood occurrence in the Nemunas River is changing its average terms from April and May to February and March. It must be mentioned that flood events became more significant during the cold period from November to January. From the other hand it must be said that recently we registered the summer floods that occurred because of heavy rains during July, 2007 and August, 2005. These facts still have no statistical importance in order to change the existing long-term trends, but their importance for the future is an object of serious discussion. Global "greenhouse effect" plays a great role in such variations occurring on the local scale.

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