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Influence of flooding on accumulation of nutrients and heavy metals in the delta of the river Nemunas in Lithuania [1]

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Abstract

Studies in the river Nemunas delta were conducted in order to evaluate the nutrient and heavy metal input to the flooded and non-flooded polders and to propose environmentally friendly farming methods. This article analyses nutrient and heavy metal accumulation in the river Nemunas delta area in the years of 1992-2000 and leaching of these compounds to various soil layers.

The analysis of nutrient accumulation showed that the soil amounts of N increased (mg kg^{-1}) about 50, P_2O_5 – 40-100, K_2O – 20-30 correspondingly. In the soil layer 20-50 cm of the non-flooded polders N the content was 4-5 times less than in flooded polders. Comparing non-flooded polders with flooded ones showed the difference in the P_2O_5 content of soils. Flooding of meadows most of all influenced K_2O. The content of K_2O increased after the flood on average 20 and 54 % in mineral soils and in peat soils respectively. After the flood 1.4-1.8 times more of K_2O appeared in the soil of a flooded polder than in a non-flooded one. Retention of nutrients during flooding of a valley were positive, both for soil fertilisation and for improvement of water quality.

Accumulation of heavy metals in the flooded polders were 20 to 40 % larger than in non-flooded ones. Distribution of Pb in soils along the river delta corresponded to the character of the sediment deposition. Closer to the river's mouth the amount of sediments as well as Pb decreased. This showed that water is cleaning itself on account of soil pollution.

To preserve existing self-purification capacity of nutrient and heavy metals it was not purposeful to reconstruct a flooded polder to a non-flooded one. Reeds, energy crops or natural wetlands should be established on swampy meadows of flooded polders.

Keywords: flood, polder, nitrogen, phosphorus, potassium, heavy metal, load

Zusammenfassung

Einfluss von Frühjahrshochwasser auf die Stoff-Akkumulation in Alliuvialböden der Nemunas-Niederung in Litauen

Das Mündungsgebiet und die Niederung des Nemunas (Memel) stellt eine einzigartige Kulturlandschaft dar. Der litauische Teil der Nemunas-Niederung umfaßt etwa 50.000 ha wovon 40.000 ha gedeicht sind. Auf 30.000 ha gibt es Sommerpolder, die während des Frühjahreshochwassers regelmäßig geflutet werden. Nur auf 10.000 ha befindet sich Winterpolder. Da das linke Nemunas-Tal im russischen "Kaliningrader Gebiet" durch Winterdeiche vor Hochwasser geschützt worden ist, überflutet das Hochwasser das rechte litauische Ufer. Bei Frühjahrshochwasser führt der Nemunas bis 7500 m^3s^{-1} ab und durch das Tal (durch Sommerpolder) strömen 20-50% der Gesamtabflusswassermenge. Vom Hochwasser werden 5-30 mg l^{-1} Schwebstoffe in suspendierter Form abtransportiert, etwa 10-30% von diesen Stoffen wird auf Grünland abgelagert. Bei Hochwasser werden in den Alliuvialböden die Konzentrationen an Stickstoff um 25 % (etwa 50 mg kg^{-1}), an Phosphor (40-100 mg kg^{-1} P_2O_5) und Kalium (20-30 mg kg^{-1} K_2O) um 40-60 % erhöht. In den Böden der Sommerpolder finden sich etwa 20 mg kg^{-1} Pb, 15 mg kg^{-1} Ni und 12 mg kg^{-1} Cr. Diese Mengen an Schwermetallen sind um 20-40 % höher als in Winterpoldern, auch um 30-90 % höher als in ähnlichen Lehmböden Litauens, aber immer noch um das Anderthalbfache niedriger als in benachbarten Ländern wie BRD, Polen, Russland.

Für die Erhöhung der Stoffakkumulation in der Nemunas-Niederung eignet sich eine Erhöhung der Wasserdurchlässigkeit des linken Tales oder auch eine Verbesserung der Sedimentations Bedingungen. Ein Teil der freizuhaltenden Winterpolderwiesen sollte daher für die Hochwasserabfuhr oder -rückhaltung benutzt werden, in überfluteten Sommerpoldern ist die Stromgeschwindigkeit zu verringern.

Schlüsselworte: Hochwasser, Überflutung, Polder, Stickstoff, Phosphat, Kalium, Schwermetalle

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1 Introduction

Nutrient and heavy metals enter rivers' valleys not only as a product of agricultural or industrial activity in the area. Chemical compounds can be brought by floodwater from all upstream basins (Kabata-Pendias et al. 1984, Alekseev 1987, Nikanorov 1989). Dissolved chemical compounds and absorbed to suspended particles matter were transported during the flood. In surface water most of the microelements were as colloidal suspensions or chemical compounds bound to organic and mineral particles. Besides that, floodwater can wash out some mobile nutrients from soil. This is why the quality of floodwater varied in very large intervals and depended mainly on the ecological conditions and the pollution of the basin. Permitted limits for concentrations of heavy metals in surface water are different (mg l^{-1}): Cr 0.03-0.05, Pb 0.05-0.1, Ni 0.05-0.075, Zn 0.01-5 (Nikanorov, 1989; DVWK 1996).

Accumulation of nutrients and heavy metals in due course of time can be much bigger in flooded valleys compared to the same type of soils and human activities in non-flooded areas.

The content of mobile and available nutrients can change in a flooded valley even within one year.

Accumulation of heavy metals is a long lasting process that is difficult to assess because of many factors and reasons affecting their runoff to valleys. Content of heavy metals in alluvial soils (fluvisol) were larger than in loamy soils of a non-flooded area (Kabata-Pendias et al., 1984). In Germany, Poland and the former Soviet Union alluvial soil averaged a content of 42-125 mg kg^{-1} Zn compared to 35-70 mg kg^{-1} in loam and clay soils and 39-63 and 25-49 mg kg^{-1} for Pb respectively. Mean differences for Ni in the same soils were only 10-23 and 10-58 mg kg^{-1}. Nutrient deposits increased alluvial soil fertility but heavy metals had a negative impact on quality of agricultural products.

The largest region of alluvial soils in Lithuania is in the delta of the river Nemunas from the Curonian Lagoon and its valley upstream to the outlet of the river Jura (fig. 1).

The delta of the river Nemunas is a very specific region having no analogues in the Baltic region (Basalykas, 1965; Grigat, 1931). Since the XVII century improvement of waterways, construction of dikes to protect the area from floods and other human activities had a great influence on hydrological conditions of the delta region. In the beginning of the XX century dikes protecting from high spring floods were constructed on the left bank of the river Nemunas and its branch Atmata in the Rusne island. The dikes were heightened twice more - on the sixth and seventh decades. Meantime flood streams were directed to the right side of the valley. Because of that flood duration and water level increased there and sedimentation of deposits intensified both in the stream and in the valley.

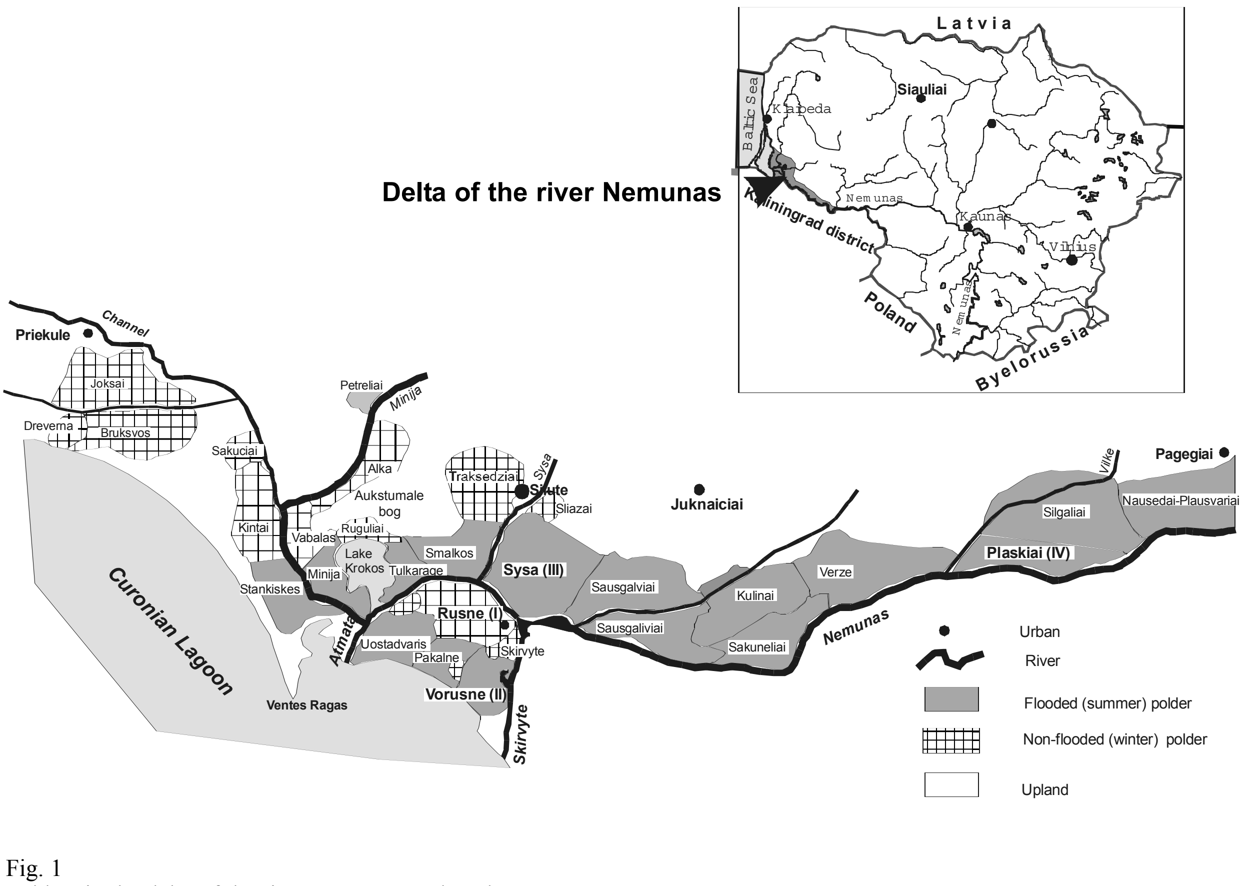

Fig. 1
Polders in the delta of the river Nemunas and study areas

Table 1
Characteristics of study areas

Polder	Area (ha)	Surface height (m)	Soil type	Amount of particles (%)		Soil Density (g cm^{-3})	Density of solid part (g cm^{-3})
				<0.002 (mm)	<0.005 (mm)		
I	906	0.5	Loam	20-25	44-50	0.8-1.1	2.4-2.6
II	776	0.3	Silt and sandy loam	22-32	65-67	0.8-1.2	2.4-2.6
III	2285	0.7	Sandy loam Peat	21-32	52-72	0.6-0.9 0.2-0.4	1.9-2.3 1.5-1.7

The right side of the valley belonging to Lithuania is an area of 60 km length and 2-8 km width that from the south is bordering to the Kaliningrad district, Curonian Lagoon - from west and arable upland with forests border northern part of the valley. Large flooded meadows vary with sandy uplands and high bogs in the valley. The surface of the valley goes down to the mouth of river Nemunas with a stream slope from 5-8 m in the upper part of the valley to 0-0.5 in the western part of the delta. The flooded area is about 40 000 ha. Human activity on the right side of flood land was needed to adapt to the high dikes on the opposite bank of the river. High non-flooded dikes were constructed to protect settlements and arable land, and low dikes were built for protection of meadows from summer and autumn floods (see fig. 1). Dikes of 10 000 ha non-flooded polders (winter polders) and 30 000 ha spring flooded polders (summer polders) make up a dike system that did not change the flood regime in the river Nemunas delta. The average discharge of the river Nemunas is 620 m^3s^{-1} and the extreme discharge with a 1 % probability is 7 500 m^3s^{-1}. A water layer of 1-4 m overflows summer polders on an average on 30 days every spring. Sometimes a flood lasts 90-110 days when strong western wind occurred for a long time or ice is crushed in the river's mouth.

During spring flood about 20-50 % of the total discharge flows in the valley and about 10-30 % of the material transported (0.2-0.5 t ha^{-1}) settled down in the summer polders (Vaikasas et al. 2000). There are about 1.5 % N, 0.3 % P_2O_5, 0.4 % K_2O in the sediments. The heavy metal content is: 2.6 mg kg^{-1} Cu, 1.5 mg kg^{-1} Pb, 8.0 mg kg^{-1} Cr, 0.1 mg kg^{-1} Cd, 1.8 mg kg^{-1} Ni and 160 Mn mg kg^{-1} (Zelionka, 1967; Gipiskis, 2000; Lithuanian Ministry of Environment, 1995-1998). Some elements could be absorbed from flood water where there is on average 0.9 mg l^{-1} of N, 0.11 mg l^{-1} P_2O_5, 3.0 mg l^{-1} K_2O and 1-10 mg l^{-1} of microelements. Because of that the delta of the river Nemunas still has great importance for the protection of the Curonian Lagoon environment.

Land use and human activity is changing in the delta area after the re-establishment of independence like allover Lithuania. After reducing of water pumping the water level has increased in the summer polders. As a consequence of the decrease of fodder consumption marginal and lower meadows were abandoned. Changes in farming practices arise possibilities for restoration of wetlands, protection of breeding and migrating birds and stimulation of re-naturalisation of grasslands in this unique area. In the context of these processes it is very important to determine the influence of floods on the quality of alluvial soils, accumulation and the distribution of nutrient and heavy metals in the delta area.

2 Material and methods

Studies of nutrients' changes before and after a flood in different types of polders and in a non-flooded area have been carried out since 1992, and for the accumulation of heavy metals since 1995. Permanent observation and sampling is organised in Rusne winter polder (I) and in Vorusne (II), Sysa (III), Plaskiai (IV) summer polders (see fig. 1). The first three are in the lower part of the valley and the fourth – in the upper part.

Light sandy and loamy sand soils arose at the riverbed and loamy soils in the central part and sub terrace of the valley.

Mainly peat soil (70 % of the polder area) is in the polder Sysa. Only at the river bed peat soil is covered with sand. Marsh sedge peat of 25-40 % decomposition and 10-40 % ash dominates in the polder. Characteristics of the surface soil layer of 10-20 cm depth are presented in the table 1. Low doses of N (60 kg ha^{-1}) are applied by the farmers and the yield of hay amounts to 4-8 t ha^{-1}.

Soil samples were taken in every studied polder from 2-3 places with three replications. This was done in the central part of the valley where most of the fine sediments and thus also chemical compounds accumulate (Gipiskis 2000). Samples for heavy metals analyses were taken from an adjacent non-flooded area in the upper slope of the terrace.

Samples for plant available nutrient analyses were taken before the flood (in autumn) and after the flood (in spring) from layers: 10-20, 20-30 and 40-50 cm in mineral soils of the polders I, II, IV and in peat soil of the polder III. Heavy metals were determined once a year from the surface soil layer of 0-10 cm.

Table 2
Mean nutrient content in 0-10 cm layer during 1992-2000 mg kg^{-1}

Polder	N hydrolytic			P_2O_5			K_2O		
	Autumn	After flood	t_{teor}* S_d	Autumn	After flood	t_{teor}* S_d	Autumn	After flood	t_{teor}* S_d
I	211.4	220.4	51.2	144.1	152.1	40.2	68.6	77.4	21.5
II	206.6	259.0	**51.2**	180.2	250.6	115.9	87.4	107.0	**18.0**
III	502.4	620.2	**117.8**	48.5	76.4	35.0	76.7	118.2	**26.0**
IV	200.3	247.6	**46.2**	200.5	301.5	**86.4**	116.6	138.1	**18.4**

Note: t_{teor} = theoretic Student criteria
S_d = error of the difference of the mean values
Figures of significant difference of 95 % probability are written in bold

Kornfild's method was used to determine N hydrolytic, the A-L method for P_2O_5 and K_2O, extraction with 2M nitric acid for heavy metals (Cr, Cd, Pb, Ni, Cu, Zn) (Lithuanian Ministry of Environment 1994).

3 Results and discussion

3.1 Change of Nitrogen content

Load of hydrolytic N before and after the flood did not change in the non–flooded (I) polder (table 2). In flooded mineral and peat soil polders N content increased by 25 % after the flood than before it (in autumn). The increase of N after the flood (in spring) in the peat soil polder is 2-3 times higher than in the polders with mineral soils. The reason might be more intensive biochemical processes in organic soils.

Cultivated meadows of non-flooded polders usually accumulate more mineral N in autumn (Adomaitis et al.1998). In spring time mineral N content in Plaskiai upland polder soil (IV) is similar to the flooded delta polder Vorusne (II).

By comparing two adjacent polders, Rusne non-flooded (I) and flooded polder Vorusne (II), it comes out that the N content in autumn was almost the same but after the flood N in the flooded polder Vorusne (II) and in Plaskiai upland polder (IV) increased significantly (95 % probability). The greatest change of N in the flooded polder occured after the flood in the 0-30 cm soil layer (fig. 2). Deeper layers nutrient content were almost constant during the study period.

A reliable relation between flood duration and N content in the soil could not be found during the study period although flood duration varied between 13 and 161 days. Coefficients of determination were not more than 0.21. The reason could be that flood duration depends not only on water level height upstream delta but also on the water inflow from the Curonian Lagoon because of strong west winds and pumping regime in the polder during winter. The concentration of minerals in water of the local polder is much lower than in the upstream runoff.

Some tendency of mineral N reduction after long lasting floods was noticed in the soil because mineral N dissolves in less mineralised flooded water and after is leached to deeper layers or through subsurface drains. This phenomenon was also noticed in the experimental model of flooded field plots (Malisauskas et al. 2000).

In mineral soils of the non-flooded Rusne polder (I) the amount of N before and after the flood was the same in the surface layer of 0-10 cm (fig. 3). This amount was very close to the N content in the surface layer of a flooded polder Vorusne (II). In the 20-50 cm soil layer of the non-

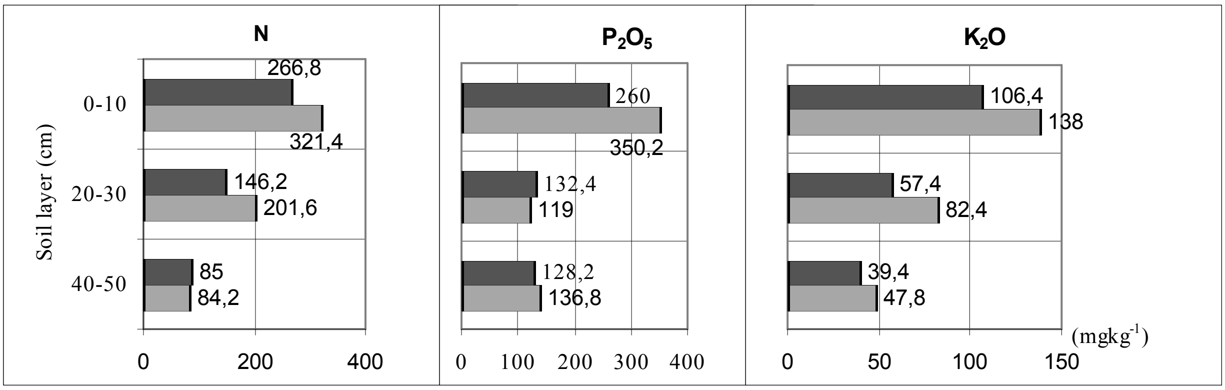

Fig. 2
Mean nutrient content in flooded Vorusne polder before the flood (autumn) and after (spring) from 1993 to 2000

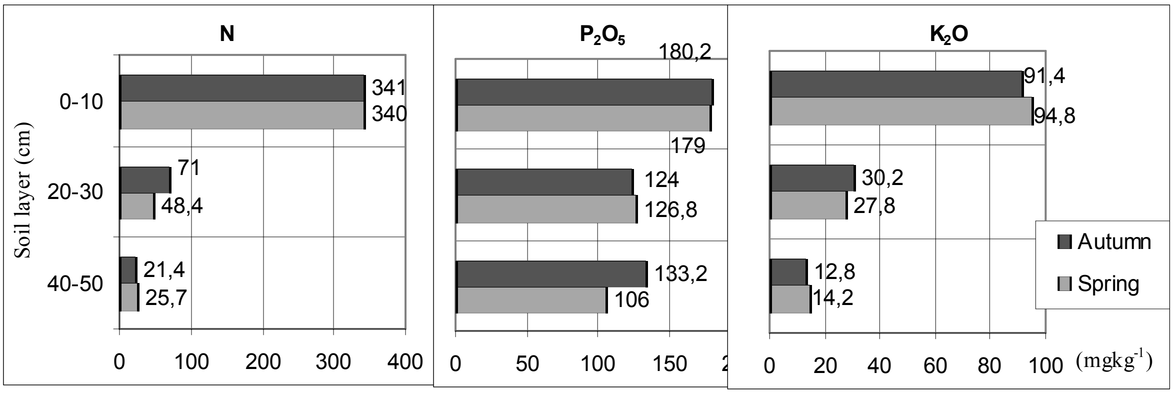

Fig. 3
Mean nutrient content in non-flooded Rusne polder before flooding (autumn) and after (spring) (1993 to 2000)

flooded polder the N content is 4-5 times lower than in the flooded polders (II, IV). The reason might be a more intensive N leaching in the non-flooded polder.

3.2 Change of phosphate content

In the non-flooded polder Rusne (I) there was no significant difference in P_2O_5 content before and after a flood (see table 2). In the flooded polders this difference is 39-57 % but the difference is not reliable because of the data variation (V=30-50 %). Significant were the differences in the P_2O_5 content (60-100 %) comparing non-flooded polders with flooded ones after a flood. Much less P_2O_5 is found in the peat soil polder (III).

In the delta's upper flooded polder Plaskiai (IV), where most of the deposits settle during a flood, the P_2O_5 content was 20 % bigger than in the river's mouth polder Vorusne (II). There is no large difference in the P_2O_5 content between separate layers (see fig. 3) in the soil profile of the non-flooded polder Rusne (I).

In the surface layer of flooded polders the P_2O_5 content was 2-3 times higher than in deeper layers. Mineral soils were rich or very rich in P_2O_5, but the peat soils are very poor, 3-5 times less P_2O_5 than in mineral soils (Malisauskas et al. 2000). The relation of the P_2O_5 content after a flood with the duration of the flood is only weak (r = 0.02 and 0.4).

Flooding of meadows influenced especially the content of K_2O. Floodwater enriched soils with K_2O very much. The content of K_2O increased after the flood on average by 20 and 54 % in mineral soils and in peat soils respectively (see tab. 2). The same relation was revealed by comparing flooded and non-flooded polders. After the flood 1.4-1.8 times more K_2O appeared in the soils of the flooded polders than in the non-flooded ones. The differences were significant in all cases. More K_2O got into the upland Plaskiai flooded polder (IV). The distribution of K_2O in the soil profile is similar with the largest content in the surface soil layer (0-10 cm), deeper layers had 1.5-2 times less. There was no relation between the changes in K_2O content and flood duration.

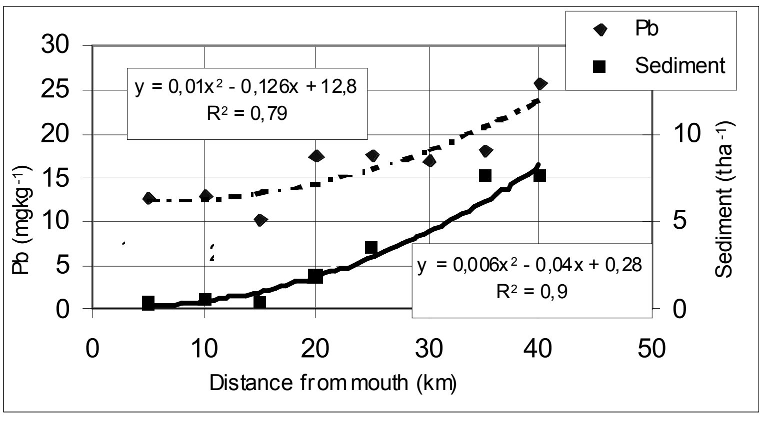

Fig. 4
Distribution of Pb (1) and sediments (2) along the river Nemunas valley in 1994

Table 3
Distribution of heavy metals in flooded and non-flooded meadows (mg kg^{-1})

Study area	Number of replications	Cu	Zn	Pb	Cr	Mn	Ni
Permitted limit		40.0	150.0	32.0	50.0	1500	50.0
				Flooded area			
Flooded (summer) polders	27	14.2 8.0-24.6	60.2 24.0-89.2	20.3 6.8-27.8	14.2 7.4-19.8	572 134-1176	15.2 8.0-25.4
Non-flooded (winter) polders	14	10.0 4.8-18.0	43.5 29.0-64.4	16.3 9.0-24.8	12.2 6.0-18.0	459 136-950	11.2 4.8-21.0
				Non-flooded area			
Nemunas delta upland	6	4.9 3.4-6.2	33.7 17.0-48.0	6.2 3.0-11.0	5.4 3.6-7.6	134 74-234	5.1 3.0-9.0
Silute district *		1.0-3.6	11.2-40.0	4.0-12.9	4.0-10.0		4.0-10.0
Kedainiai district (Middle of Lithuania**)		10.5 4.0-20.0	31.5 17.0-59.0	12.0 5.4-17.8	11.9 4.0-21.0		10.5 4.0-27.6

Note: Mean value are in the numerator, min and max values are in the denominator
* (Lithuanian Ministry of Environment 1998)
** (Lithuanian Ministry of Environment 1998, Lubyte et al. 1996)

3.3 Distribution of heavy metals

Load of Pb distributed along the river's delta correspondingly to the character of sediment deposition (fig. 3). More Pb settled down in the upper part of the delta where more turbid floodwater overflows the valley. Closer to the river's mouth the amount of sediments as well as Pb decreases. The same was in the case of other heavy metals' distribution. Most of the heavy metals settled in the soils of the flooded polders (tab. 3).

The amount of most heavy metals are several times less than the permitted limit in Lithuania (PL). Only the load of Pb was higher and maximum values are close to permitted limit. Content of heavy metals in non-flooded polders, that are protected from flood for 40-70 years, are already significantly (20-40 %) lower than in flooded polders. But large differences occured between the amount of heavy metals in the never flooded delta upland and flooded polders (tab. 3).

Light soils dominate in the delta of the river Nemunas. Accumulation of heavy metals (Pb, Chr, and Ni) in light soils are usually lower than in loam or clay (Kabata-Pendias 1984, Alekseev, 1987). The heavy metal accumulation correlated with the clay content (r = 0.3-0.6). The amount of heavy metals in the turf podsolic loamy soil of the Kedainiai district was 1.3-1.9 times lower than in alluvial loamy soil of similar texture in the delta of the river Nemunas.

4 Conclusions

1. Flooding of the Nemunas valley improves farming conditions as well as it preserves the natural retention capacity for pollutants. The amount of nutrients during the observation period increased as follows: N: 50, P_2O_5: 40-100, K_2O: 20-30 mg kg^{-1}.
2. Accumulation of heavy metals in the flooded polders was 20-40 % higher than in non-flooded ones. The content of heavy metals in the flooded soils was 30-90 % higher compared to upland soils of the same texture.
3. Retention of nutrients during flood in a valley is positive both for soil fertilisation and for improvement of water quality. Accumulation of heavy metals should be evaluated in two ways: water is cleaning itself on account of soil pollution.
4. To preserve the self-purification capacity for nutrients and heavy metals it is not needed to reconstruct a flooded polder to a non-flooded one. To increase the retention of nutrients and heavy metals in the valley it is pur-

poseful to analyse the possibility to open some polders for flooding in the left side valley of the river Nemunas.
5. Swampy meadows, especially in areas with heavy metal accumulation, have to be taken out of agricultural use. Reeds, and cropping of energy plants could be grown here or natural wetlands could be restored.

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