ENVIRONMENTAL ENGINEERING

The 8th International Conference
May 19–20, 2011, Vilnius, Lithuania
Selected papers

ISSN 2029-7106 print / ISSN 2029-7092 online
ISBN 978-9955-28-828-2 (2 Volume)
ISBN 978-9955-28-827-5 (3 Volume)
http://enviro.vgtu.lt

IMPACT OF ANTHROPOGENIC ACTIVITIES ON RIVER WATER QUALITY IN THE REGION OF LIELUPĖ RIVER BASIN DISTRICT

Rasa Ruminaite

Vilnius Gediminas technical university, Saulėtekio ave. 11, LT-10223 Vilnius, Lithuania.
E-mail: rasa.ruminaite@vgtu.lt

Abstract. The article analyses sources of point and scattered pollution and their change, also change of runoff and biogenic substances in the rivers Mūša, Lėvuo, Tatula and Nemunėlis, located in a particularly sensitive karst region of Lielupė river basin district (RBD). The research was performed over the period from 1992 to 2009 with various intensity of anthropogenic activity. The most hazardous sources of pollution were determined by analytical and statistical methods, the tendency of their change was analysed also their impact on the river water quality was assessed.
It was found that upgrading of wastewater treatment plants reduced the release of total nitrogen by 29 %, ammonium nitrogen by 13 %, nitrate nitrogen by 32 % and total phosphorus by 27 % over the period from 1992 to 2009. As the number of animals being bred dropped by 55 %, the load of total nitrogen and total phosphorus from livestock farms decreased by 51 %.

Keywords:.rivers, point and scattered sources of pollution, runoff, biogenic substances.

1. Introduction

Based on scientific research carried out abroad and in Lithuania (Gailiušis *et al.* 2001; Pauliukevičius 2006; Kyllmar *et al.* 2006; Vuorenmaa *et al.* 2002) it has been determined that the water quality mainly depends on the properties and amounts of pollutants released into water bodies, and the main chemical pollutants of the rivers are organic substances as well as nitrogen and phosphorus compounds that come from industrial, agricultural and domestic sectors due to insufficient wastewater treatment, management and control. Anthropogenic activities are the cause of water pollution and eutrophication of the rivers.

Anthropogenic activities determine around 90 % of the annual amount of total nitrogen and around 78 % of the annual amount of total phosphorus carried over by Lithuanian rivers (Povilaitis 2008). Depending on variation of the agricultural land area in the river basin, nitrogen load may increase or decrease by 1.5 to 2 times (Pauliukevičius 2007).

Poor water quality in the rivers of the Northern part of Lithuania is mainly (around 60–80 %) conditioned by scattered source pollution: agricultural activities and residential buildings not connected to wastewater network. During the last decade, the average amount of total nitrogen and total phosphorus coming from arable land to Mūša river basin was 87 % and 36 % respectively, from treatment plants households and built-up areas 10 % and 49 % respectively, and from areas of forests and pastures 3 % and 15 % respectively (Ruminaitė *et al.* 2009, 2010). This is confirmed by the scientists who have investigated washout of biogenic substances into water bodies in karst region (Morkūnas *et al.* 2005; Tumas 2003). They have determined that it is essential to assess the type of agricultural land and state that the smallest amount of nitrate nitrogen is washed out from the area of pastures, and the largest amount from arable lands. Anthropogenic loads on water bodies are caused also by point source pollution, i.e. pollutants discharged from municipal wastewater treatment plants, industrial facilities, rain water drainage (Juozapaitis and Zelionkienė 1997).

Impact of anthropogenic activities on the environment is negative, and it is impossible to protect properly the river water from pollution and to avoid possible ecologic problems without regulation of economic and industrial activities, without isolation of pollution sources.

The objective of research is to assess impact of anthropogenic activities on the surface water quality of the rivers located in the karst region of Lielupė river basin district (RBD) sensitive to pollution.

2. Research subject and methodology

Impact of anthropogenic activities on river water quality was assessed in the rivers Mūša, Lėvuo, Tatula and Nemunėlis of Lielupė river basin district (Fig 1) over the period 1992 to 2009.

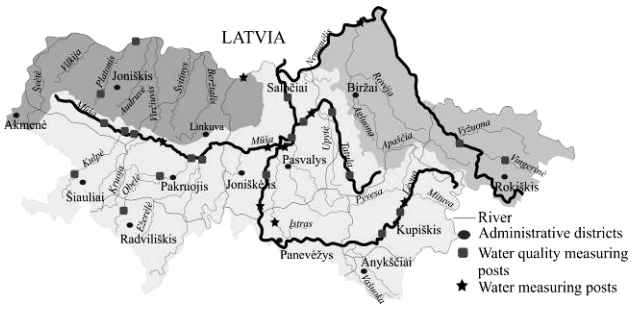

Fig 1. The region of Lielupė river basin and the network of the rivers investigated

Geological conditions of the investigated river basins are complicated due to karst phenomena. Karst processes are particularly active in Biržai district and Pasvalys district. The soils in the basin are among the most fertile soils in Lithuania, therefore an intensive agriculture is very common here.

The following branches of industry are the most developed here: food industry, grain processing, manufacturing of composite feed, wood processing and furniture, peat extraction, textile, concrete, ceramics, bicycles manufacturing.

The number of population connected to wastewater systems is relatively high in large cities and makes 70 % at the average, meanwhile this number is moderate in small settlements (around 50 %).

Variations of runoff and water quality of the rivers of Lielupė river basin district over the period 1992 to 2009 has been analysed. The number of operating industrial and agricultural enterprises and their distribution in the area has been determined based on the data of the Department of Statistics of Lithuania.

The data of water flow measurements collected by the Lithuanian Hydrometeorological service was used for analysis of the wateriness of the rivers. Hydrological observations of the river Mūša were carried out in Miciūnai and Ustukiai, Lėvuo – Pasvalys and Kupiškis, Tatula – Trečionys, Nemunėlis – Tabokinė water metering stations. Observations were carried out every day, the data of Panevėžys and Biržai meteorological stations located closest to the rivers investigated were used to characterise meteorological conditions.

A long-term observation data accumulated by the Environmental Protection Agency was used for analysis of river water quality. Water samples for determining of water quality were taken every month at the water quality metering station in Lėvuo river at the mouth, in Tatula – at Trečionys and in Nemunėlis river at Panemunys, also in Mūša river downstream from Saločiai. Based on this data, variations over time of nitrogen and phosphorus compounds (concentrations and loads) were assessed, the number of occasions, when concentrations of biogenic substances exceeded the established class of good ecological condition according to the values of the indicators of physical-chemical quality elements, was established.

The change of pollution with biogenic substances over the year in relation to runoff was assessed according to a mean weighted concentration (Gaigalis *et al.* 2006):

$$k_i = \frac{k_1 \cdot q_1 + k_2 \cdot q_2 + ... + k_n \cdot q_n}{\sum_1^n q(t_n)}, \quad (1)$$

where: k_i – mean weighted concentration of all analysed i years; k_1, k_2, k_n – monthly concentrations; q_1, q_2, q_n – mean monthly flows; $\sum_1^n q(t_n)$ – the sum of flows over the estimated time period t_n.

In order to assess the extent of pollution, mean annual quantities of nitrogen and phosphorus compounds from point sources and scattered sources of pollution were estimated.

3. Results of research

Point sources and scattered sources of pollution and their change. The analysed period in the industry and agriculture of Lithuania was changeable. The number enterprises affecting the environment and water quality in the area of investigated river basins decreased by more than 16 % over the period from 1992 to 2009 (Fig 2).

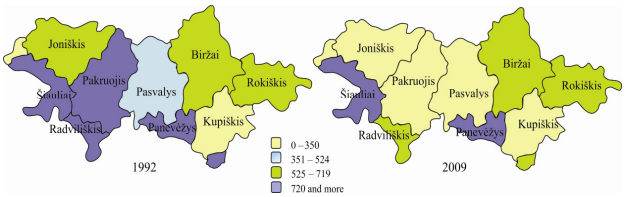

Fig 2. Territorial distribution of the enterprises functioning in the Lielupė RBD, unit

Analysis of statistical data showed that the number of small, medium and large enterprises operating in the area of the investigated river basins decreased from 5000 to 3549, i.e. by 24 %, over the period from 1992 to 2004. After 2006, situation started changing and in 2009 there were 4019 enterprises engaged in various activities. I means that the number of operating enterprises decreased by 16 % over the period from 1992 to 2009.

Release of pollutants into surface water bodies decreased along with the decrease of the number of operating enterprises. Another reason suggesting that pollution of open water sources has reduced over the last decade is upgrading, reconstruction and construction of new wastewater treatment plants of higher capacity with additional nitrogen and phosphorus removal.

The quantity of pollutants released into the water of the investigated rivers over the period from 1992 to 2009 varied significantly (Fig 3). Over the period from 1992 to 2009, the amount of total nitrogen decreased by 29 % or 636 t/year, the amount of total phosphorus and ammonia nitrogen by 27 % and 13 % or by 95 t/year and 411 t/year respectively, the amount of nitrite nitrogen by 10 %, and nitrate nitrogen by 32 %.

Construction of new and reconstruction of the existing wastewater treatment plants improved wastewater treatment efficiency. Positive developments in wastewater treatment are reflected by reduced quantities of pollutants discharged together with wastewater.

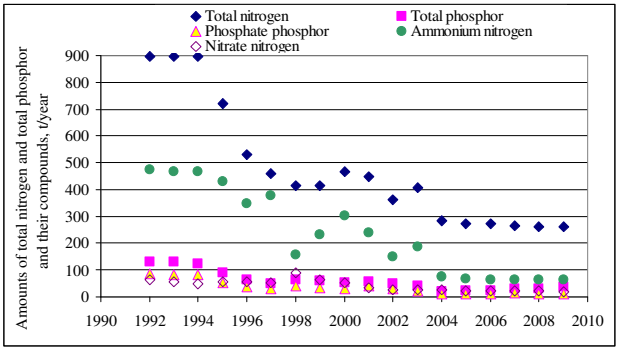

Fig 3. Amounts of total nitrogen and total phosphor and their compounds discharged in the investigated river basins within the period of 1992–2009, t/year

Agricultural land makes over 53 % of the total area of the country, and even up to 72 % of the area in the river basins investigated, therefore condition of agrarian ecosystems is particularly important here. The number of farms and companies engaged in agricultural activities in the investigated area decreased from 259 (in 1992) to 105 (in 2009), i.e. by 40 % (Fig 4).

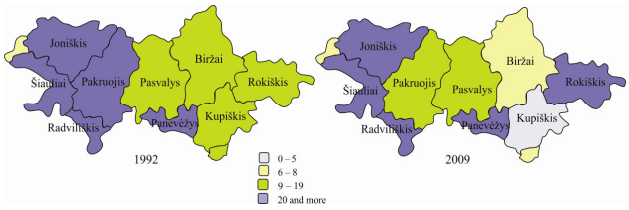

Fig 4. Territorial distribution of agricultural enterprises functioning in the Lielupė RBD, unit

While point sources of pollution have a considerable impact on the aquatic environment, but the major part of nitrogen still comes to the rivers from scattered sources. Prevalence of private property decreased the area of intensively cultivated agricultural land in the investigated river basins by around 30 %. Significant changes were incurred by the livestock sector. During the investigated period, from 1992 to 2009, average livestock density in Lielupė RBD decreased from 60.4 (in 1992) to 33.2 (in 2009) per one hectare of the basin. The most problematic and difficult situation is in Mūša sub-basin, where the largest agricultural areas are located, and also large pig farms have been built.

The impact of livestock farms on the size of pollution loads is significant. It was found that along with the decrease of livestock number in the basin, the amount of pollution resulting from manure of animals that gets into soil decreases proportionally (Table 1). The amount of total nitrogen and total phosphorus decreased by 51 % over the period from 1992 to 2009.

Table 1. Pollution load caused by livestock in the investigated rivers basins

Load pollution	Years							
	1992	1996	1998	2000	2002	2004	2006	2009
Total nitrogen								
t/year	50058	47449	37911	29263	29884	31551	32405	25735
kg/ha	55.94	53.02	42.36	32.70	33.39	35.26	36.21	28.76
Total phosphor								
t/year	8510	8066	6444	4974	5080	5363	5508	4375
kg/ha	9.51	9.01	7.20	5.56	5.68	5.99	6.16	4.89

It was found that 39.70 kg/ha of total nitrogen and 6.74 kg/ha of total phosphorus at an average was getting into the soil with manure of animals in the investigated basins during the investigated period. The Environmental Protection Agency found that 30 % of nitrogen and 25 % of phosphorus generated with manure of animals and getting into the soil reaches open water basins.

Variation of concentrations and quantities of biogenic substances. Concentrations of nitrogen and phosphorus pollutants flowing down the rivers mainly depend on the river runoff, which, in its turn, depends on meteorological conditions. Therefore, it is necessary to assess variation of runoff and conditions of its formation, while analysing long-term tendencies of river water quality variation.

One of the main factors influencing the amount of runoff is rainfall. According to the data of Panevėžys meteorological station, the nearest to Lėvuo basin, the average annual rainfall over the period from 1992 to 2009 was 591 mm (close to the norm), and according to the data of Biržai meteorological station, the nearest to Tatula, Nemunėlis and Mūša basins, it was 614 mm (slightly above the norm of 605 mm). 1996 was the driest year in the investigated basins (according to precipitation amount) – 447 mm according to the data of Panevėžys meteorological station, and 513 mm, according to Biržai meteorological station, and 1988 was the wettest year (871 mm and 870 mm, or 1.45 times more than normal).

During the investigated 18-year period, the minimum runoff in all investigated rivers was found at the beginning of the investigated period, in 1996, as well as in 2000, 2003, 2004. The runoff was only 38–84 % of the norm. The maximum runoff was established in 1998, when it exceeded the norm by 1.61 to 3.21 times. Comparison of the change of the mean annual runoff in the rivers being investigated with the variation of precipitation quantity during the analysed period, revealed similarities in the character of variation of runoff and precipitation, variation of runoff corresponds to variation of precipitation.

Analysis of the variation of the rivers runoff enables analysis of the tendency of the river water pollution variation dependence on the runoff size. It is not the only factor influencing the river water pollution, but it is rather significant, therefore it is important to assess this dependence as accurately as possible. Mean weighted concentrations are used for this purpose.

Having determined mean weighted concentrations of biogenic substances, it was found that weighted concen-

trations of ammonia nitrogen (NH_4–N) were below 1.0 mg/l before 1998, and since 1998 started decreasing (to 0.07 mg/l). Significant increase of mean weighted concentrations of ammonia nitrogen (to 2.24 mg/l) was observed in dry 1996. Mean weighted concentrations of nitrate nitrogen also increased significantly (to 5.52 mg/l) in dry 1996, and decreased (to 1.94 mg/l) along with runoff increase in 1998. After 2004, mean annual concentrations of nitrate nitrogen in the investigated rivers decreased by 6–31 % compared to 2000. It could be explained by the fact that emission of total nitrogen, including nitrates, from point sources of pollution, decreased by 1.7 times in 2005 compared to 2000 in relation to industry downturn, and a higher runoff of the rivers enabled dilution of pollutants. Mean weighted concentrations of phosphate phosphorus in these rivers vary from 0.10 to 0.64 mg/l during the years of lower runoff, and decreases to 0.04 mg/l during the years of high runoff.

Concentration of biogenic substances in the river water may increase significantly due to anthropogenic factors. Therefore in order to improve river water quality in this region sensitive to human activities, sustainable agriculture should be developed with more focus on wastewater treatment in rural areas, and improvement of water treatment facilities operation.

The amplitudes of variation of biogenic matter concentrations (mg/l) and the number of concentrations that do not comply with the indicators of good ecological status (as a percentage of the total number of samples) are presented in the Table 2. It shows that concentrations in all investigated rivers varies quite a lot and, unfortunately, is often higher than the good ecological status indicator values. The widest range of variation was found for nitrate nitrogen. For example, the lowest nitrate nitrogen concentration (0.02 mg/l) measured in Nemunėlis river water over the period of 1992 to 2009 was more than 505 times smaller than the measured maximum (10.1 mg/l) nitrate concentration. In Mūša river, this difference amounts to 405, in Lėvuo to 275, and in Tatula to 60 times. Variation of ammonium nitrogen concentrations is also high, particularly in Nemunėlis, where the maximum NH_4-N concentration (3.4 mg/l) was more than 1113 times higher than the minimum (0.003 mg/l) concentration.

A significant variation of ammonia nitrogen concentrations suggest that there may be such sources of pollution in the river basin, which do nor release pollutants regularly, ant when they do, high ammonia nitrogen concentrations are measured. In Lėvuo river this difference between the maximum and minimum concentrations of ammonia nitrogen was 300, in Tatula – 285, in Mūša – 170 times. The analysis of phosphate phosphorus concentrations variation, it was noticed that it was not as large as of nitrogen compounds. The difference between the maximum and minimum concentrations of phosphate phosphorus concentration sin Tatula, Nemunėlis and Mūša rivers accounted for 32–54 times, and in Lėvuo river – 235 times. Phosphorus pollution of Lėvuo river basin mainly depends on the population and on the industrial activities carried out here. Lėvuo flows across the boundaries of Kupiškis, Panevėžys, as well as Pasvalys towns and districts, with over 130 thousand population and intensive industrial activities. Therefore Lėvuo receives effluent from the wastewater treatment plants of towns, villages and industrial enterprises, which accounts for the major part of phosphorus pollution from point sources of pollution. The changing volume of industrial activities varies directly quantities of discharged industrial wastewater and concentrations of nitrogen and especially phosphorus in wastewater. It is likely that variation of phosphate phosphorus concentrations in the river Lėvuo is the greatest for this reason.

Table 2. The amplitudes of variation of biogenic matter concentrations (mg/l) and the number of samples exceeding the indicators of good ecological status in percent

Upė	NH_4–N	NO_3–N	PO_4–P
Lėvuo	0.013–3.9	0.04–11.0	0.02–4.7
Tatula	0.007–2.0	0.20–11.9	0.02–1.08
Nemunėlis	0.003–3.4	0.02–10.1	0.02–0.77
Mūša	0.01–1.70	0.02–8.1	0.010–0.32
Values of the indicators of good ecological status, mg/l	0.10–0.20	1.30–2.30	0.050–0.090
The number of samples exceeding the indicators of good ecological status in percent of the total number of samples			
Lėvuo	22	52	74
Tatula	20	42	54
Nemunėlis	17	45	71
Mūša	13	44	24

During 1992–2009, the number of samples, where ammonia nitrogen concentration exceeded the indicators of good ecological status, was 13–22 %, for nitrate nitrogen – 42–52 %, phosphate phosphorus – 24–74 % of the total number of samples. If the number of samples, exceeding the indicators of good ecological status at the beginning of the period, in 1992, is compared to that at the end of the period, in 2009, it appears that in 2009, when decreased the amount of pollutants released from point sources of pollution (by 10–32 %) and the amount of pollutants originated from manure of animals (by 51 %), the number of samples exceeding these indicators also decreased. The number of samples exceeding the indicators of good ecological status for ammonia nitrogen decreased by 7–10 % of the total number of samples, for phosphate phosphorus by 5–10 % of the total number of samples in 2009 compared to 1992.

In many cases, the number of the rivers complying with the indicators for good ecological status increased at the end of the period, this can be related to reduction of scattered pollution, reduction of the areas of intensive agriculture, use of fertilisers, number of livestock in the farms, also with a better treatment of wastewater discharged from point sources of pollution, and with increasing upgrading of wastewater treatment plants.

Intensive agriculture is being developed in the investigated river basins, and the area of forests that could reduce pollution of the rivers with both nitrogen and phosphorus compounds is small. It was found out that the amounts of both nitrogen and phosphorus compounds varied highly during the investigated period. The mean annual amount of ammonia nitrogen over the period from 1992 to 2009 to Mūša river was 49.1 t/year. Amount of ammonia nitrogen to Mūša river basin decreased by almost 6 times in 2009 compared to that in 1992. However, this variation of ammonia nitrogen vas not that high, as to Lėvuo river, where the mean annual amount (during the investigated period) of NH_4–N was 22.9 t/year, and in 2009 it was 9.6 times lower compared to 1992. The similar ammonia nitrogen variation tendency is observed as well to Tatula and Nemunėlis rivers, where the mean annual amount of ammonia nitrogen over the period from 1992 to 2009 was 45.4 and 30.3 t/year, and in 2009 it decreased by 6–7 times compared to 1992. (Fig 5).

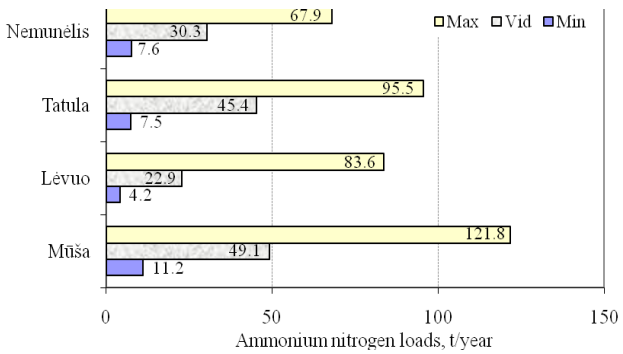

Fig 5. Ammonium nitrogen minimum, maximum and average loads

It was found that the tendency of decrease of ammonia nitrogen amount was characteristic to the rivers investigated. The decrease of ammonia nitrogen in the investigated river basins started in 1998. It corresponds to large decrease in number of livestock. Pollution decreased along with the decrease of livestock farms and the number of livestock in them.

Analysing variations of the amount of nitrogen compounds from all pollution sources in the region, it was determined that nitrate nitrogen makes the largest part of nitrogen compounds released into the rivers. The mean annual amount of nitrate nitrogen to Mūša river over the period from 1992 to 2009 was 336.8 t/year, to Lėvuo – 195, to Tatula – 175.6, and to Nemunėlis – 153.3 t/year (Fig 6).

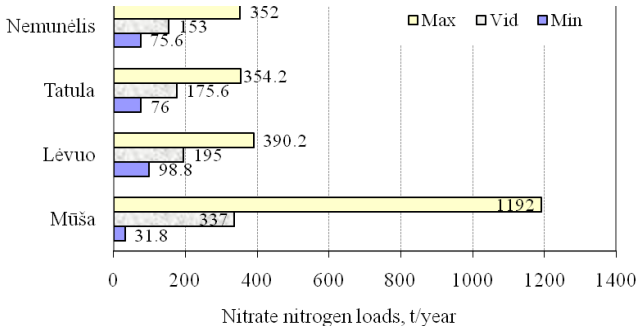

Fig 6. Nitrate nitrogen minimum, maximum and average loads

The largest amount of nitrate pollution comes to Mūša river basin, it could be explained by the size of the basin, which is the largest of the basins investigated, with the larger number of population. Based on the information provided by the municipalities, about 30–40 % of the total number of population whose wastewater is not collected in a centralised way lives in Mūša river basin. Mūša also gets large load of pollution from point sources. Šiauliai, Pakruojis, Radviliškis wastewater treatment plants with the highest capacity in the region discharge their effluent into the rivers of this basin. The amount of nitrates in the investigated rivers decreased by 3 times over the period from 1992 to 2009. The nitrate nitrogen decrease tendency was observed, when analysing the investigated period.

The phosphate phosphorus decrease tendency is also undoubted. It could be explained by decrease of the amount of industrial and domestic wastewater from towns and settlements, better wastewater treatment efficiency and reduction of the number of livestock. The mean annual amount of phosphate phosphorus in Mūša river was 13.3 t/year, in Lėvuo – 21, Tatula – 12.2, and in Nemunėlis – 8.2 t/year during the period from 1992 to 2009 (Fig 7).

The amount of phosphate phosphorus decreased by 4 times due to renovation and upgrading of wastewater treatment plants. The results obtained correspond to the results of research obtained in the neighbour countries. In Latvia, where, as Stålnacke (Stålnacke *et al.* 2004) states,

the amount of phosphorus was mainly decreased through industry downturn and modernisation of wastewater treatment plants.

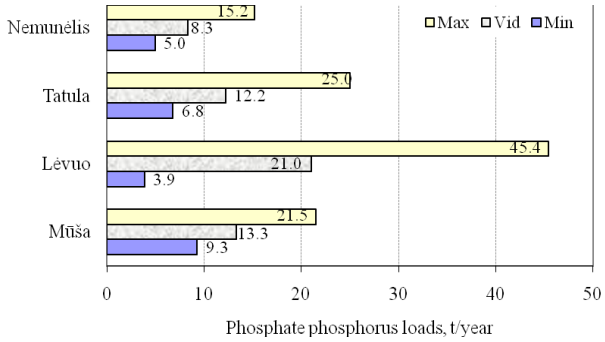

Fig 7. Phosphate phosphorus minimum, maximum and average loads

Based on the results of the analysis carried out, with consideration of the variable structure of agricultural lands, the situation in livestock farming, intensive change of market conditions and upgrading of wastewater treatment plants, it was determined that the loads both of nitrogen and phosphorus compounds from point and scattered pollution sources was steadily decreasing during the period from 1992 to 2009.

4. Conclusions

Due to upgrading of wastewater treatment plants, the amount of total nitrogen discharged from them into surface waters of the rivers investigated decreased by 29 %, the amount of total phosphorus and ammonia nitrogen by 27 % and 13 %, the amount of nitrate nitrogen by 32 % during the period from 1992 to 2009.

It was found out that in Lielupė RBD the mean amount of 39.70 kg/ha of total nitrogen and 6.74 kg/ha of total phosphorus got into the soil with manure of animals during the period from 1992 to 2009. As the number of animals being bred dropped by 55 % during the period from 1992 to 2009, the load of total nitrogen and total phosphorus from livestock farms decreased by 51 %.

As the anthropogenic load decreased, the number of samples exceeding the indicators of good ecological status in percent of the total amount of samples decreased: for ammonia nitrogen by 7–10 %, for nitrite nitrogen by 2–3 %, for phosphate phosphorus by 5–10 % in 2009 compared to 1992.

It was determined that as pollution discharged from scattered sources (10–32 %) and from manure of animals(51 %) decreased during the investigated 18 years period, the amount of nitrogen compounds decreased by 3–9 times, and phosphorus compounds by 2–4 times. This shows that change of economic-industrial activities influences greatly pollution loads.

References

Gaigalis, K.; Šileika, A. S.; Šmitienė, A. 2006. Azoto ir fosforo koncentracijų kaita žemės ūkio veikiamuose upeliuose. *Vandens ūkio inžinerija*, 30(50): 44–56.

Gailiušis, B.; Jablonskis, J.; Kovalenkovienė, M. 2001. *Lietuvos upės. Hidrografija ir nuotėkis* [Lithuanian rivers. Hydrograph and runoff]. Kaunas, 794 p. ISBN-9986-492-64-5.

Juozapaitis, A.; Zelionkienė, V. 1997. Practical issues concerning determination of the anthropogenic influence on changes of elements of river basin water balance and measures for their solutions. *Lietuvos žemės ūkio universiteto ir Lietuvos vandens ūkio instituto mokslo darba*i, 3(25): 78–81.

Kyllmar, K.; Carlsson, C.; Gustafson, A.; Ulen, B.; Johnsson, H. 2006. Nutrient discharge from small agricultural cachments in Sweden. Characterisation and trends, Agriculture. *Ecosystems & Environment*, 115: 15–26.

Morkūnas, V.; Rudzianskaitė, A.; Šukys, P. 2005. Influence of agriculture on soil water quality in the karst region of Lithuania. *Irrigation and Drainage*, 54: 353–361.

Pauliukevičius, H. 2006. Effect of land use on the runoff. *Water Management Engineering,* 30(50): 88–94.

Pauliukevičius, H. 2007. Middle Lithuanian rivers flow simulation by AnnAGNPS model. *Water Management Engineering,* 32 (52): 53-59.

Povilaitis, A. 2008. Source Apportionment and Retention of Nutrients and Organic Matter in the Merkys river Basin in Southern Lithuania. *Journal of Environmental engineering and landscape management,* 16(4): 195-204.

Ruminaitė, R.; Šileika, A. S.; Lukianas, A. 2009. Analysis of Pollution of the Musa Catchment with Total Nitrogen. *Ecology,* 55 (2): 112-120.

Ruminaitė, R.; Šileika, A. S. 2010.FYRIS model application for analysis of total phosphorus pollution in the musa catchment. *Water Management Engineering,* 36(56): 41–49.

Stålnacke, P.; Grimvall, A.; Libiseller, C.; Laznik, M.; Kokorite, I. 2003. Trends in nutrient concentrations in Latvian rivers and response to the dramatic changes in agriculture. *Journal of Hydrology*, 283: 184–199.

Tumas, R. 2003. Lithuanian karst region rivers water ecology: hydrochemical and hydrobiological evaluation. *Nordic Hydrology* 35 (1): 61–72.

Vuorenmaa, S.; Rekolainen, S.; Lepisto, A.; Kenttamies, K.; Kauppila, P. 2002. Losies of nitrogen and phosphorus from agricultural and forest areas in Finland durning the 1980 and 1990. *Environmental Monitoring and Assessment,* 76: 213–248.