RESULTS OF FIELD STUDIES ON NITROGEN AND PHOSPHORUS INPUT FROM AGRICULTURAL PRODUCTION TO SELECTED WATER BODIES IN WESTERN DVINA

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Abstract. In 2017 a field study of water bodies in Nevel and Usvyatsky Districts of Pskov Region was aimed to give qualitative and quantity estimation of the impact of local large-scale pig enterprises on the status of water bodies in the Western Dvina river basin. Water samples were taken and the flow was measured on the vulnerable areas and outside the farm impact area in accordance with an elaborated programme and methods of field measurements. Soil samples were collected from the fields, where liquid pig manure was applied. The results showed that on the local level, in the vicinity of these fields, the water bodies featured high levels of main manure pollution indicators – ammonium nitrogen and phosphorous. The concentration of ammonium varied from 4.4 to 32.7 mg·l^{-1} at these points that was several hundred times higher than that in water bodies in natural areas; the concentration of dissolved phosphorus varied from 0.11 to 0.23 mg·l^{-1} that was several times higher than the background values. The concentration of these elements was dropping down to the background level with the distance from the fields as the result of self-purification and dilution processes owing to natural conditions, associated mainly with the presence of wetlands.

Keywords: nitrogen, phosphorous, pollution, pig industry, Western Dvina.

Introduction

The main branch of agricultural production, which has development prospects on the territories in the Western Dvina River basin, is animal farming, which contributes to an increase in nutrient diffuse load. The mass of gross nitrogen and phosphorus in organic fertilisers applied in 2016 amounted to 4,510 tons and 1,023 tons, respectively. Taking into account the planned increase in the animal stock and, consequently, the yield of manure, the gross nitrogen mass will be 5705 t per year and the gross phosphorus – 1333 t per year at the projected level of 2020 [1]. The growth in manure volumes leads to higher amount of nitrogen and phosphorus and, accordingly, to bigger area of agricultural land needed for application of all the resulting organic fertilisers.

Major agricultural facilities, pig rearing complexes included, which generate large masses of liquid manure, are a particular threat to environmental security and the level of diffuse load on the Russian part of the territory under investigation. Pig rearing complexes apply modern animal housing practices and manure removal technologies (mainly gravity systems), which produce the manure with 93-96% moisture content, 2.3-2.5 kg·t^{-1} nitrogen content and 0.6-0.8 kg·t^{-1} phosphorus content [2]. Currently, within the boundaries of the Russian part of the Western Dvina catchment area, there are 9 production sites with intensive pig rearing, where 267021 pigs are housed at any one time [3], which can be expressed as 80 thousand livestock units. Even if all agricultural areas in the municipal districts where pig complexes are situated will be used, the animal density will be approximately 23 livestock units per hectare - significantly higher than for other large enterprises in the Baltic Sea region [4].

IEEP methodology was used to estimate diffuse nutrient load from agriculture to waterbodies in the Russian part of the Western Dvina catchment area [5]. Annual nitrogen and phosphorous loads from agriculture production to the water objects in Pskov Region within Western Dvina catchment area are 76 ton of nitrogen and 11 ton of phosphorous. It should be noted that within the methodology it is assumed that all manure is evenly applied and there is significant uptake with yields. However, taking into account that there is lack of areas for application of all manure produced by pig complexes, the possibility of additional negative impact, not included in the methodology, should be investigated.

To assess the pollution risk of water bodies by the waste from large-scale pig complexes a series of field studies on individual watercourses was conducted in Usvyatsky (457 km^2 within Western Dvina catchment) and Nevelsky (1400 km^2 within Western Dvina catchment) Districts of Pskov Region, which are the areas with the highest concentration of pig farms.

Materials and methods

The field studies included the following tasks:

- preconnaissance survey of the territories adjacent to large-scale pig complexes in Nevelsky and Usvyatsky Districts to specify the zone of possible exposure to nutrient loading from the facilities of developing pig complexes located in the watershed of the Western Dvina and Lovat River basins;
- determining the presence of natural water bodies in the surveyed area, not associated with the livestock complexes and other possible objects of anthropogenic load with the aim to use them as reference (background);
- random measurements of water flow in the watercourses adjacent to the territory of pig complexes and capable of receiving the point source waste water and non-point wastewater from manure storage facilities;
- sampling of water to measure the nitrogen, potassium and phosphorus content in the above watercourses.

The field studies were performed from 8 to 10 August 2017 by two teams – from the Institute for Engineering and Environmental Problems in Agricultural Production (IEEP) and from the State Hydrological Institute (SHI).

After processing of cartographic materials and space images, the points for water sampling and water flow measurements were identified. Tables 1 and 2 include coordinates of sampling points for IEEP team and SHI.

To take into account the regional peculiarities of the nutrient content in natural waters, both field groups determined the content of these substances in transboundary rivers Ushcha and Usvyacha, as well as in forest streams, presumably not affected by pig complexes.

IEEP field group collected water and soil samples, some of which were analysed in the field; others were preserved and sent for further analysis to the IEEP laboratory. Chemical analysis of water samples was carried out using certified methods.

SHI team was engaged in hydro-ecological examination of water objects, including water sampling and water flow measurements.

Results and discussion

Table 1 presents the results of water flow measurements by SHI team.

Table 1

Position of water sampling points and flow measurements made by SHI team

Date	Water body	Position data, degree		Q, $m^3 \cdot s^{-1}$
		latitude	longitude	
08.08	Untitled stream from irrigation fields near Tretiakovo Village	56º01′45.4″	29º44′08.2″	0.0038
	Vonstva River – Velikoje Selo	56º00′21.0″	29º41′57.8″	0.172
	Ushcha River – Turki Perevoz	56º03′00.8″	29º32′25.4″	7.95
	Untitled stream from untitled lake flowing to Ushcha River	56º04′44.0″	29º32′37.7″	0.0026
	Ushchanka River – Talankino	56º12′12.7″	29º35′21.2″	2.46
09.08	Usvyacha River between Ozeron Lake and Ordosno Lake	56º01′45.3″	30º57′24.9″	2.18
	Usvyacha River – Titovo	55º55′17.4″	31º02′43.5″	1.02
	Usvyacha River – Tserkovishche	55º53′43.4″	30º51′11.3″	2.32
	Untitled stream flowing to Uzmen Lake from South-West	55º44′21.8″	30º42′36.4″	0.0017
	Watercourse from Uzhanye Lake to Bolshije Glyshi Lake – Prudishche	55º46′25.7″	30º41′41.8″	0.178
	Uzmen River – Usvyaty	55º44′44.1″	30º43′48.3″	0.523
	Usvyacha River – Karpenkino	55º41′02.0″	30º46′17.1″	2.82
	Usvyacha River – Kozlovo	55º45′29.0″	30º47′42.9″	2.46

Table 1 (continued)

Date	Water body	Position data, degree		Q, $m^3 \cdot s^{-1}$
		latitude	longitude	
10.08	Untitled stream – Antropovo	55º45′47.0″	30º47′37.5″	0.0065
	Untitled stream from pig complex Blinki to Zaverezhie Lake	55º54′49.0″	29º59′23.0″	0.00
	Untitled stream from pig complex Kosenkovo to Zaverezhie Lake	55º54′34.4″	29º58′19.1″	0.082
	Yezerishche Lake – Lobok	55º52′18.6″	29º58′39.9″	-
	Well b Kublanovo Village	55º59′55.8″	30º01′25.3″	-
	Lovat River – Polibino	56º08′47.5″	30º23′44.1″	9.882

The water flow measurement results (SHI data) show that the water flows in forest streams during the examination varied from 0 to 0.082 $m^3 \cdot s^{-1}$; in Ushcha and Ushchanka Rivers – from 2.46 to 7.95 $m^3 \cdot s^{-1}$; in Usvyacha River – from 1.02 to 2.82 $m^3 \cdot s^{-1}$. It should be noted that the measurements took place in summer low water season under the lack of rains. Ushcha catchment area is 1707 km^2; Usvyach is 1343 km^2.

The water sampling was designed in such a way that the content of nutrients in the watercourses adjacent to the territory of enterprises could be compared with the concentrations of these components in the natural water bodies located at a significant distance from the objects with adverse impact. Location of the sampling points can be found in Figure 1. In addition, in order to assess the possibility of migration of these substances through the hydrographic network, the samples were taken in the water bodies located in the Uzmen Lake basin, at various distances from the fields irrigated with liquid pig manure. Sampling results from upstream cross-sections on Ushcha ans Usvyacha rivers (far from pig complexes), as well as on small forest rivers, unaffected by human activities, were used as reference background values.

Table 2

Description of sampling points (IEEP team data)

Sampling point number (IEEP)	Position data		Sampling date	Notes (sample type)
	latitude	longitude		
1	56.029394	29.737572	08.08.17	Area affected by pig complexes (Nevelsky District)
2	56.016922	29.660258	08.08.17	Area affected by pig complexes (Nevelsky District)
3	56.050545	29.543058	08.08.17	Background content (reference) (Nevelsky District)
4	56.029258	30.956831	09.08.17	Background content (reference) (Usvyatsky District)
5	55.988579	31.059550	09.08.17	Background content (reference) (Usvyatsky District)
6	55.853768	30.778131	09.08.17	Area affected by pig complexes (Usvyatsky District)
7	55.860046	30.782244	09.08.17	Background content (reference) (Usvyatsky District, Uzhitsa River)
8	55.832372	30.732082	09.08.17	(Uzhitsa river, around 3 km from the irrigation fields of pig complexes)
9	55.819689	30.722065	09.08.17	(Uzhitsa river, around 6 km from the irrigation fields of pig complexes)
10	55.818169	30.721321	09.08.17	Water from a well to assess the impact of pig complexes on the groundwater

Table 2

Sampling point number (IEEP)	Position data		Sampling date	Notes (sample type)
	latitude	longitude		
11	55.818169	30.726028	09.08.17	Area affected by pig complexes
12	55.801103	30.713057	09.08.17	Area affected by pig complexes
13	55.766341	30.723893	09.08.17	Area affected by pig complexes
14	55.742148	30.692522	09.08.17	Area affected by pig complexes
15	55.745515	30.731625	09.08.17	(water exchange between lakes - to assess the impact of pig complexes)
16	55.831205	30.734398	10.08.17	Background content (reference)

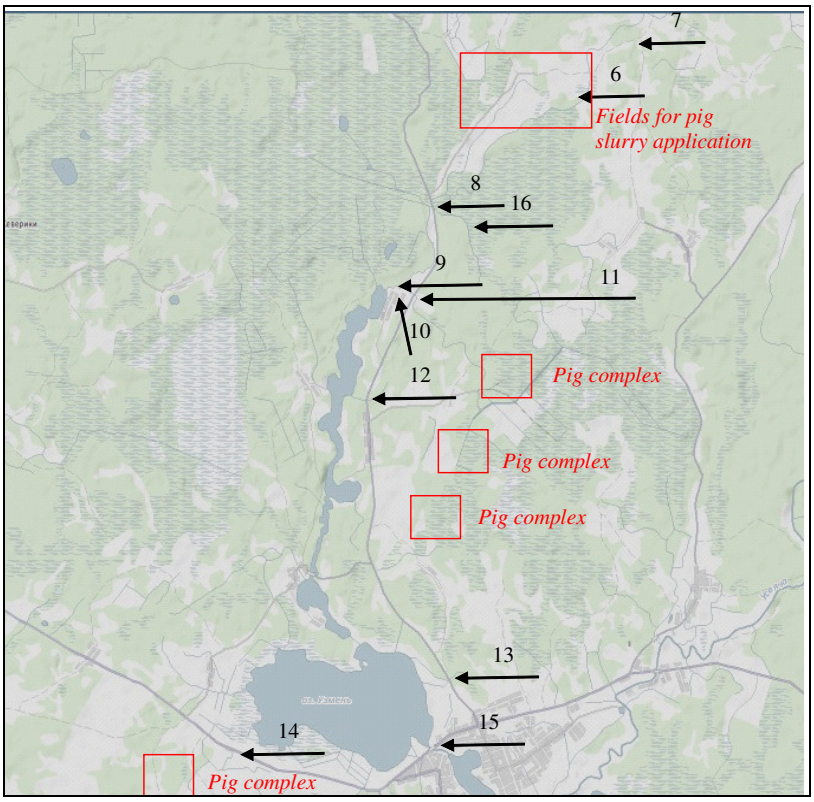

Fig. 1. **Layout of sampling points in Uzhitsa River catchment**

The effect of pig complexes was estimated by indicator substances associated with liquid pig manure pollution – ammonium nitrogen, phosphorus and potassium. The obtained results were compared with the maximum permissible concentration of pollutants (MPC) in fishery water objects [6] as well as with the average concentrations of these substances in background points (MPC is not established for potassium), as shown in Fig. 2-4.

The field study findings show that the chemical composition of water in the water bodies, located in the immediate vicinity of pig complexes and fields for manure (wastewater) spreading, differs from that in remote forest streams. As can be seen in Fig. 3 and 6, the samples from points 1, 2, 6, 9, 11, 12, and 14 have much higher content of ammonium nitrogen, nitrate nitrogen and potassium. In view of this, the significant impact of pig complexes on the nearby water bodies is verified. The quality of water in the well, located in the zone of possible pig complex impact, does not reveal the presence of groundwater contamination.

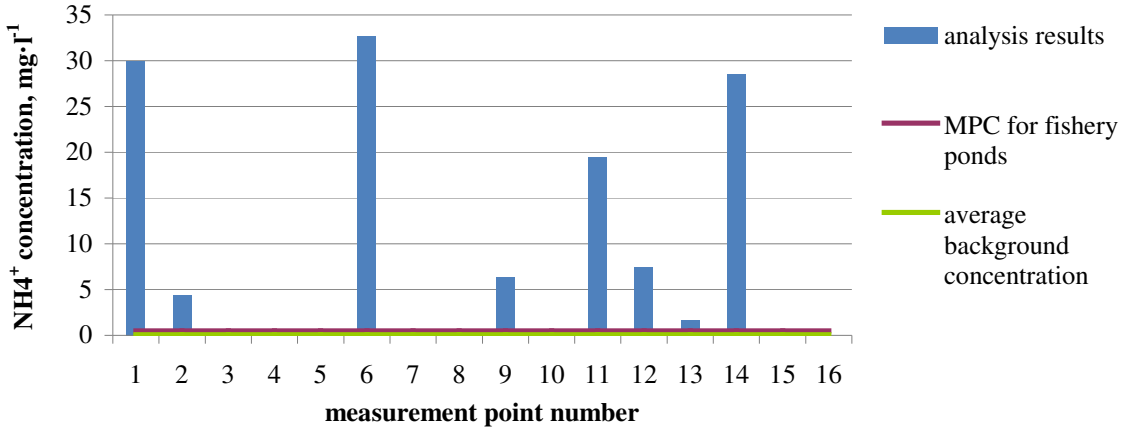

Fig. 2. **Measured water concentration of ammonium ion:** MPC = 0.5 mg·l^{-1}

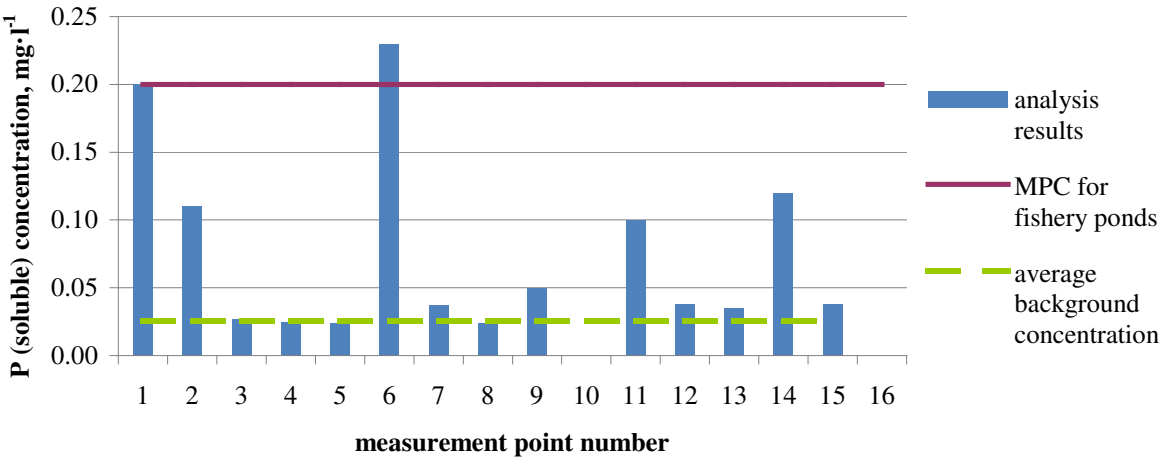

Fig. 3. **Measured water concentration of soluble phosphorous:** MPC = 0.2 mg·l^{-1}; concentration hasn't been measured in 16th point

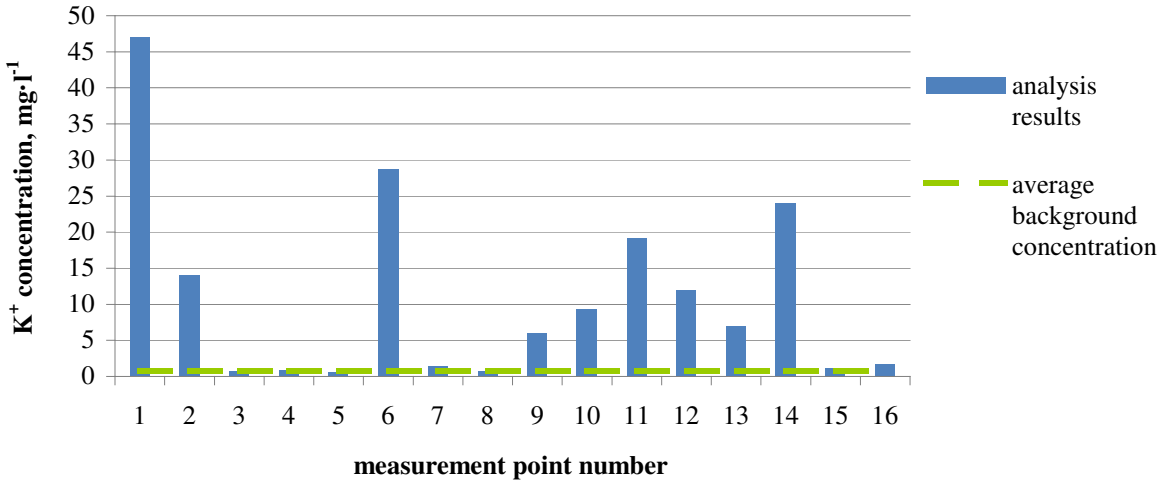

Fig. 4. **Measured water concentration of potassium ion:** MPC not established

Analysis of nutrients migration with the watercourse of Uzhitsa River, which is exposed to the effect of the fields in its middle course, showed that local pollution in the immediate vicinity of these objects significantly reduced just 3 km from them, both as a result of additional water supply with forest inflowing streams, and in connection with the possible water cleaning, when passing the swamps. In this respect, the quantity of swamps should be noted as a specific feature of the study area.

The measurement results suggest that today the swamps act as a natural filter on the way of nutrients to the water bodies and reduce the nutrient content in the water to the natural background level.

It should be noted that at the time of survey, no manure was spread on the fields. The water flow in the lower course of Uzhitsa River was practically zero. It can be expected that manure spreading in wet weather conditions will significantly increase the range of nutrient migration with the water of Uzhitsa River.

The study also included the soil sampling on the fields, where manure was applied, which were located in Uzhitsa River basin and affected water sampling point No,6. The analysis results are shown in Table 3.

Table 3

Results of soil analysis (IEEP data)

Sample number	Date of sampling	Moisture content, %	Nutrients content, mg·kg^{-1}					Notes
			$N_{total.}$ (in terms of NH_4^+)	NH_4^+	K^+	P (0.2N HCL)	$P_{gross.}$	
1	10.08.17	19.3	1466	26.80	202.3	225.2	872	Probably manure was applied last year
2	10.08.17	24.4	1066	18.46	176.1	189.9	1680	-
3	10.08.17	35.9	2650	12.30	146.3	353.6	1570	A site with a lot of pig manure in hollows
4	10.08.17	21.1	1066	13.4	211.4	197.7	754	Relatively recent manure application

The soil study showed that there was significant accumulation of nitrogen and phosphorus in the fields, where pig manure was applied; in the future this would result in a sharp increase in the input of nutrients to the nearby watercourses. For this not to happen, these farmlands need to be used reasonably and effectively, achieving maximum removal of nutrients with the harvested crops.

Conclusions

1. In all collected water samples in the area affected by the pig complexes, the concentrations of ammonium nitrogen significantly exceeded the MPC; relatively high concentrations of phosphorus were also found, almost 10 times exceeding the background levels that indicated the presence of significant local pollution with liquid pig manure in the vicinity of irrigation fields.
2. Analysis of nutrient migration with the waterways, affected by agricultural lands, showed that local pollution in the immediate vicinity of these sites significantly reduced in a few kilometres, both as a result of additional water inflow from the relatively clean tributaries and in connection with possible water self-cleaning. The swamps act as a natural barrier to the migration of nutrients from the soil spread with liquid pig manure. However, their accumulative capacity is difficult to assess, so this process must stay under control.
3. Substantial accumulation of nitrogen and phosphorus was registered in the fields, where pig manure was spread; in the future it could lead to a sharp increase in the supply of nutrients to the nearby watercourses.

Acknowledgement

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