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Possible Nutrient Load Reduction on the Large River Catchment Due to the Best Available Techniques Introduction in Agricultural Production

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Abstract: The study aimed to assess the possible reduction of the nutrient load and nitrogen and phosphorus losses from the Russian part of the Irtysh River catchment, one of our country's largest transboundary rivers, by implementing the best available techniques (BAT) in agricultural production. The Institute of Limnology Load Model (ILLM) mathematical model of nutrient load on the river watershed was used to solve the problem. Information on the primary sources of the nutrient load was collected for the entire Russian part of the Irtysh River catchment and tributaries catchments: Om, Ishim, Tobol, and Konda rivers. Agricultural activity of more than 800 enterprises concentrated mainly in the southern part of the Russian basin was analyzed. The calculations show that the most significant reduction of agricultural nutrient load due to BAT implementation is achieved in the Russian part of the catchment area of the Tobol River (31% for nitrogen and 25% for phosphorus from the total load on the catchment). The nutrient load can be reduced by 23% of nitrogen and 18% of phosphorus due to BAT implementation from the entire catchment of the Irtysh River (Russian part), which will lead to a corresponding reduction in a nutrient run-off by 13% of nitrogen and 4% of phosphorus. Therefore, a significant decrease in nutrient transport by river flow cannot be expected. However, it is essential to confirm the possibility of nutrient load reduction through the implementation of BAT, aiming at the transition to modern production technologies by minimizing the impact on the environment and maintaining the economic efficiency of agricultural production.

Keywords: nutrient load, modeling, river basin, best available techniques

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Research Article

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1. Introduction

The input of different substances from anthropogenic sources causes pollution and anthropogenic eutrophication of the water bodies. Agricultural activity is a significant source of diffuse (dispersed anthropogenic) pressure on watersheds and their primary hydrographic network [*HELCOM*, 2022] and is recognized as the main source of diffuse input of nutrients into water bodies [*HELCOM*, 2018; *Sandström et al.*, 2020].

According to the results of recent studies, nitrogen losses vary widely, ranging from 6.6 to 100 kg ha^{-1}. In most cases, the transport to water bodies falls within the range of 20 to 45 kg ha^{-1} [*Chen and Bechmann*, 2019; *Jansson et al.*, 2019b; *Kaur et al.*, 2017]. The specific phosphorus input, as determined by research in the Baltic region countries, varies between 0.15 and 1 kg ha^{-1} [*Jacobsson*, 2012].

Several studies indicate the primary importance of improving manure management to reduce nutrient surplus and the associated risks of water body eutrophication [*Buckwell and Nadeu*, 2016; *Oenema et al.*, 2007; *Tybirk et al.*, 2013].

One main direction for improving intensive agricultural production's environmental safety is introducing the best available techniques (BAT). These include [*GOST R*

56828.15-2016, 2019] technological processes, methods, and procedures for organizing the production, performance of work, or provision of services, including environmental and energy management systems, as well as design, construction, and operation of structures and equipment, which ensure reduction and (or) prevention of environmental pollution and waste production, compared to the current level. Using BAT is the most effective way to ensure environmental quality standards and standards of permissible environmental impact, considering economic and technical feasibility. BAT related to nutrient load reduction in agriculture includes technologies for processing and storing manure from livestock farms and poultry farms, as well as organic and mineral fertilizers application techniques in accordance with agrotechnical requirements.

Previous studies have shown that the introduction of best available techniques in manure management can lead to a reduction in diffuse nitrogen losses by 16.8% in the Leningrad region and 14.7% in the Kaliningrad region. Similarly, for phosphorus, the reduction can reach 9.1% and 8.4% respectively in these regions.

Similar studies conducted for the Baltic Sea region have shown that the maximum reduction of nitrogen loss resulting from improvement of manure management system can reach 10% of the current impact level [*Jansson et al.*, 2019b]. Reduction in production capacity and the share of cultivated agricultural land in EU countries, in the absence of financial incentives, can lead to a reduction in nutrient load ranging from 0.5% to 4%, depending on the basin [*Jansson et al.*, 2019a].

The study aimed to assess the possible reduction of the nutrient load and nitrogen and phosphorus losses from the Russian part of the Irtysh River catchment, one of our country's largest transboundary rivers, by implementing the best available techniques in agricultural production.

2. Study Area

The main object of study is the Russian part of the Irtysh River basin [*Nizhne-Ob Basin Water Administration*, 2014], one of the most important transboundary rivers of the Russian Federation with a complex water management situation. It flows through the territory of China and Kazakhstan in its upper and middle reaches. The Irtysh basin is impacted by the extraction and processing of natural resources, metallurgical, chemical-metallurgical, and chemical production, engineering, as well as the presence of energy facilities, major cities, transportation infrastructure, and agricultural production, which are sources of local and diffuse water pollution. The situation is further aggravated by the irreversible water intake from the Kar-Irtysh River within Chinese territory and the regulated flow within the borders of Kazakhstan. As a result, regions within the territory of Russia are experiencing a deficit of water resources against the backdrop deteriorating water quality. Until now, nutrient and pollution loads assessments haven't been carried out. These circumstances hinder the development of ecologically justified management decisions aimed at improving the environmental conditions in the considered basin.

Within Russian Federation, Irtysh River catchment includes territories of the Omsk, Chelyabinsk, Kurgan, Sverdlovsk, Novosibirsk, Tyumen regions, and the Khanty-Mansi Autonomous Okrug. The minor part of the catchment belongs to Perm region, the Orenburg region, and the Republic of Bashkortostan. Most of the basin is in the steppe and forest-steppe area, with only a relatively small lower part of the basin lying in the forest area. From the state border to Omsk, the Irtysh River does not have large tributaries. Within this stretch, the riverbed is winding and unstable, with multiple channels. The width of the valley varies from 5 to 19 km, narrowing to 2 km near Omsk, and the floodplain has numerous old riverbeds and lakes. From Omsk to Tobolsk, the Irtysh receives major tributaries such as the Om and Ishim rivers resulting in the widening of the valley to 6–8 km and the formation of large river deltas. Below the confluence with the Tobol River, the Irtysh flows north through the most marshy part of the West Siberian Plain. The width of the valley expands to 10–20 km. Near the mouth, the riverbed widens to 1.2 km, becomes multi-channeled, and contains islands. The water supply is mixed, including snowmelt, rainfall, and groundwater. The average annual water discharge at Ust-Kamenogorsk is 590 $m^3\,s^{-1}$. Chemical composition studies of the Irtysh River water at the Khanty-Mansiysk site [*Pozdnyakov et al.*, 2022] from 1987 to 2020 revealed significant fluctuations in the nitrogen and phosphorus content over the long-term series, occasionally exceeding regulatory values. No consistent directional changes in these series were observed. The concentrations of inorganic forms of nutrients varied within the following ranges: $N-NH_4^+$ – 0.089–1.53 $mg\,L^{-1}$, $N-NO_2^-$ – 0.003–0.044 $mg\,L^{-1}$, $N-NO_3^-$ – 0.017–0.395 $mg\,L^{-1}$, and phosphorus as phosphates – 0.019–0.146 $mg\,L^{-1}$. Most of the territory is occupied by sod-podzolic, chernozem, and peat soils. The proportion of solonchaks, located in the steppe zone, is high, accounting for about 14% of the total basin area. Heavy soils (clayey and loamy) dominate 90% of the watershed area [*Pozdnyakov et al.*, 2022].

The Russian part of the Irtysh catchment has been divided into seven hydrographic units (sub-basins) as shown in Figure 1, namely: 14.01.01 – the Irtysh River at Ust-Ishim (Russian part of the basin); 14.01.02 – Om River; 14.01.03 – Ishim River (Russian part); 14.01.04 – the Irtysh River from Ishim to Tobol; 14.01.05 – Tobol River (Russian part); 14.01.06 – Konda River; 14.01.07 – the Irtysh River from Tobol to the Ob (Figure 1).

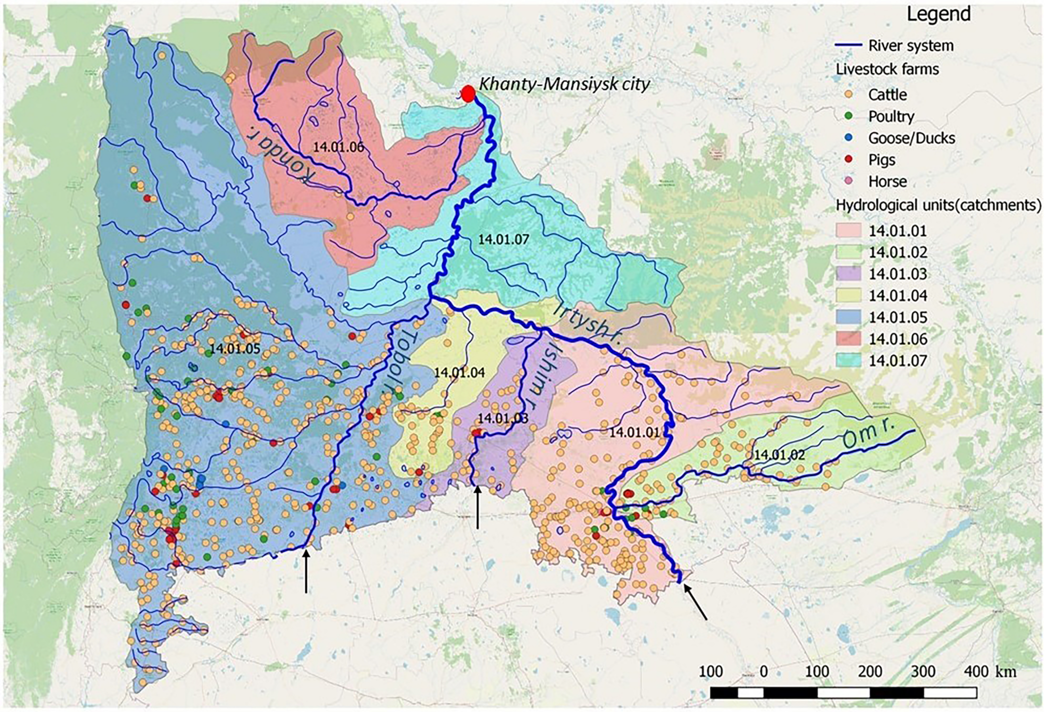

Figure 1. A scheme of the Russian part of the Irtysh River used to determine nutrient and pollution loads on the river system per hydrographic units: 14.01.01 – the Irtysh River at Ust-Ishim (Russian part of the basin); 14.01.02 – Om River; 14.01.03 – Ishim River (Russian part); 14.01.04 – the Irtysh River from Ishim to Tobol; 14.01.05 – Tobol River (Russian part); 14.01.06 – Konda River; 14.01.07 – the Irtysh River from Tobol to the Ob.

3. Material and Methods

In the first stage, the exact location of more than 800 agricultural enterprises, concentrated mainly in the southern part of the Russian part of the basin, has been determined (Figure 1). Input data regarding the use of nutrients within the studied area have been collected and analyzed. As defined during research, there are mega-large cattle farms with a population of over 8000 heads and mega-large pig farms. There are 744 cattle farms with overall population more than 970,000 heads. Additionally, there are 65 poultry farms, with a total poultry population exceeding 66 million heads. The remaining facilities are dedicated to pig farming, with population of over 3 million heads. The largest enterprises are located in the Sverdlovsk, Tyumen, and Chelyabinsk regions.

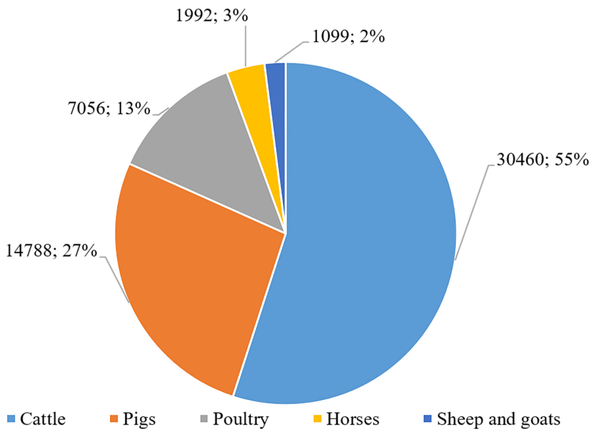

Figure 2. Amount of manure produced in the Irtysh River basin by animal category in 2021, thousand tons.

Most farms lack waterproof storage for manure and organic fertilizers. Finally, areas with high pig and poultry density per agricultural area have been identified.

Data on the amount of manure produced in the Irtysh River basin are presented on Figure 2.

As indicated in Figure 2, over 55% of the total manure produced by large cattle farms. Analysis of satellite imagery has shown that more than 90% of the cattle farms lack impermeable manure storage facilities, which can lead to increased soil and water pollution.

An analysis of agricultural activities within the sub-basins of the Irtysh River has revealed uneven distribution of agricultural facilities, predominantly located in the southern parts of the sub-basins.

Nutrient losses and transport have been quantified using the Institute of Limnology Load Model (ILLM), accomplished by Methodology developed in the Institute for Engineering and Environmental Problems in Agricultural Production (IEEP) – branch of FSAC VIM [*Briukhanov et al.*, 2016, 2018; *Kondratyev and Shmakova*, 2019; *Pozdnyakov et al.*, 2020, 2022].

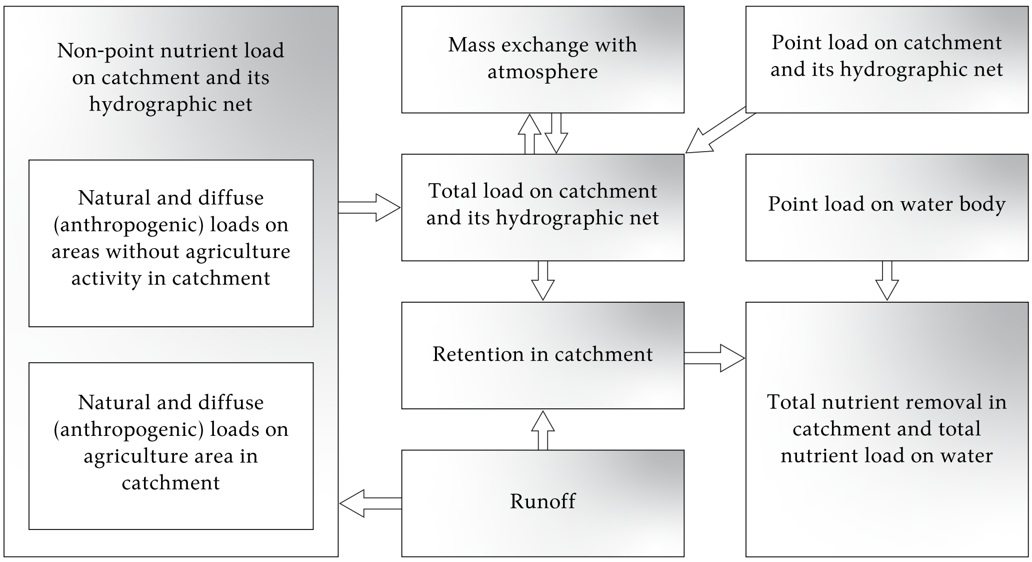

Figure 3. Algorithm for quantifying overall nutrient load by the ILLM model.

The ILLM model has been included in the list of models and methods used by the Contracting Parties of HELCOM to quantify nutrient loads from the Baltic Sea catchment area [*Svendsen*, 2019].

The main components of the external nutrient load on a water body (L) are (Figure 3): losses from unmanaged lands considered as natural background load (L_e), nutrient losses originating from agricultural activities (L_{agr}), point sources discharging to the surface waters on the catchment (L_{P1}) and directly to the receiving water body (e.g. lake, sea) (L_{P2}), as well as mass exchange with the atmosphere (L_a) [*Kondratyev*, 2007; *Kondratyev and Shmakova*, 2019]:

$$L = \left(L_e + L_{\text{agr}} + L_{P1} + L_a\right)(1 - k_r) + L_{P2}, \tag{1}$$

where k_r is the dimensionless coefficient defining the nutrient retention by the catchment and hydrographic network. All other components of equation (1) have a [t year^{-1}] dimension.

Methods for setting input values and the ILLM model parameters are described in detail in [*Kondratyev and Shmakova*, 2019]. The types of underlying watershed surfaces were classified for information support of the model. The instrument was the United Nations Land Cover Classification System (LCCS) based on images from the PROBA-V (PROBA-Vegetation) and Sentinel-2 satellites. Surface types were combined to obtain five classes, which are necessary for calculating the load on a water body: 1 – floodplains, meadows, forest-steppe; 2 – agricultural areas; 3 – urban areas and other anthropogenic landscapes; 4 – forest, swamp; 5 – permanent water bodies. The emission characteristics of total nitrogen and total phosphorus loss with the runoff from each type of underlying surface were estimated based on the analysis of literature data [*Lobchenko et al.*, 2016; *Vtorova et al.*, 2000; *Yakutina*, 2014].

The average annual runoff for years of 5%, 50%, and 95% duration flow is calculated according to the method described in Code SP 33-101-2003 for cases then hydrometric observations data are available [*SP 33-101-2003*, 2004]. Information collected from statistical reporting forms of the State Water Register online database for the period 2009–2020 (form 2.11-gvr) was used to obtain values of point source discharges to receiving river system on the studied catchment. Average annual precipitation of total phosphorus from the atmospheric was determined based on known geostatic dependencies [*Kondratyev and Shmakova*, 2019].

As a rule, a significant part of pollutants entering the catchment area from various sources does not reach the mouth of large rivers due to retention in the hydrographic network. The following equation has been used to estimate nutrient retention in the river system [*Behrendt and Dannowski*, 2005; *Kondratyev and Shmakova*, 2019]:

$$k_r = k^* \left(1 - \frac{1}{1 + aq^b}\right), \tag{2}$$

where k^* is a calibration parameter that considers the local features of nutrient retention, a and b are dimensionless empirical parameters. Specific run-off q can be determined by runoff y (mm year^{-1}) by following relation $q = 0.03171y$.

Methodology for calculating the diffuse load of nitrogen and phosphorus originating from agricultural activities on the catchments and the potential for its reduction due to BAT introduction in agriculture, developed by the Institute for Engineering and Environmental Problems in Agricultural Production (IEEP) – branch of FSAC VIM, was used to calculate nitrogen and phosphorous losses from agriculture-related sources (L_{agr} in equation (1)). According to this methodology, the diffuse load of nitrogen (N) and phosphorus (P) from farming in the Russian part of the Irtysh River are calculated by the following equation :

$$L_{\text{agr}} = 10^{-3} \sum_{i=1}^{n_1} A_i (M_{\text{soil}\,i} K_1 + (\alpha_1 M_{\text{min}\,i} + \alpha_2 M_{\text{org}\,i}) K_6) K_2 K_3 K_4 K_5, \tag{3}$$

where, L_{agr} is the load generated in the farm fields and entered the nearest watercourse (t year^{-1});
$M_{\text{soil}\,i}$ is the nutrient content in the field topsoil of the i-th farm (kg ha^{-1});
$M_{\text{min}\,i}$ and $M_{\text{org}\,i}$ are the doses of mineral and organic fertilizers applied to the fields of the i-th farm (kg ha^{-1});
A_i is the agricultural land area of the i-th farm (ha);
α_1 and α_2 are the coefficients of nutrients entering the runoff, taking into account the uptake of mineral (1) and organic (2) fertilizers by crops;
K_1 is the coefficient characterizing the nutrients loss from the topsoil;
K_2 is the coefficient of the distance between the agricultural land and the hydrographic network;

K_3 is the coefficient indicating the type of soil by origin;
K_4 is the coefficient representing soil texture;
K_5 is the coefficient that takes into account the farm type and the farmland structure;
K_6 is the coefficient describing the compliance of organic and mineral fertilizer application technology with relevant BATs.
All coefficients are dimensionless.

The Methodology involves collecting of detailed information on agricultural activities and natural conditions on the territory under study and does not require special field measurements. After primary analysis and processing using GIS technologies, official open-source statistical data are used as input data in the information Methodology.

The factor of applying BAT for the utilization of manure takes into account the influence of the machinery technologies used and compliance with regulations regarding runoff of nitrogen and phosphorus contained in organic fertilizers. The following BATs were considered in assessing the impact of this factor:

- Application of organic and mineral fertilizers using intelligent machines equipped with special working tools, a process monitoring system with automatic adjustment of parameters and operating modes;
- Incorporation of organic fertilizers into the soil using soil tillage machines that ensure thorough mixing with the soil;
- Creation of buffer strips on cultivated fields near water bodies;
- Implementation of technological regulations and establishing application rates for manure based on nitrogen and phosphorus content in organic fertilizers, considering soil characteristics (e.g., nutrient content), seasonal requirements of cultivated crops, and weather or field conditions that may lead to runoff occurrence.

A complete list of agro-engineering and organizational requirements for complying with BATs is included in the Russian reference documents “NDT-ITS NDT-41” and “NDT-ITS NDT-42” for intensive pig and poultry farming, approved by the orders of Rosstandart No. 2819 dated 13.12.17 and No. 2667 dated 29.11.17.

The Methodology has the following assumptions and restrictions: a) quantification is performed for average water runoff conditions; b) statistical data about fertilizer application, collected based on the municipal district level, are used for different parts of the district based on the assumption about the similarity of agricultural activities; c) possible natural variability of the coefficients within the considered homogeneous areas has not been taken into account, although the weighted average value of the field’s distance from the primary hydrographic network is considered; d) the nutrient load reduction potential due to BAT introduction is assumed to be the same for all categories of livestock farms; e) it was assumed that all farms comply with the basic requirements of the legislation regarding the storage, processing, and application of manure, although in actual conditions significant violations of environmental requirements are often observed during manure management, leading to pollution of water bodies. In such cases, the environmental effect of the BAT introduction can be significantly higher.

4. Results

Diffuse load of N and P originating from farming activities on water bodies in the Russian part of Irtysh River in 2021 was calculated using the algorithm of the Methodology (equation 3) and input data collected from state databases and processed in GIS.

Based on calculations, the annual nitrogen and phosphorus load on water bodies for the year 2021 has been determined, along with specific losses per hectare of agricultural land. The highest nutrient losses is observed from agricultural lands in the Tobol River basin (16 kg ha^{-1} of nitrogen and 0.81 kg ha^{-1} of phosphorus), while the lowest values are found in the lower part of the Irtysh River basin before its confluence with the Ob River (6.2 kg ha^{-1} of nitrogen and 0.28 kg ha^{-1} of phosphorus).

Quantification of the nutrient run-off with the Irtysh River near Khanty-Mansiysk averaged for 2009–2020 is presented in Table 1. The main components of the load from the Russian part of the Irtysh River's catchment are calculated by the ILLM model. ILLM model calibration was carried out according to the observational data in the cross-section in the city of Khanty-Mansiysk, located at Irtysh River mouth for a 50% duration flow conditions.

Table 1. Nutrient input (t year^{-1}) in the city of Khanty-Mansiysk cross-section for average flow (82.9 mm year^{-1})

Parameter	N_{tot}	P_{tot}
External input (transboundary)	26,770	1162
Point sources	27.4	7681
Agriculture	113,926	5630
Deposition from atmosphere	0	3285
Loss from different types of areas (except agricultural)	59,871	9778
The total load on the river system	200,594	27,537
Retention by the river system	76,798	16,792
Modeled input from the catchment	**123,795**	**10,744**
Nutrient input in the river mouth based on Roshydromet data	**124,034**	**10,888**
Diffuse sources input	69,388	3097
Input from natural background sources	37,869	2914
Point sources input	16.9	2997
Transboundary input	16,520	453
Input from atmosphere	0	1282
Retention coefficient, dimensionless	0.382	0.609

As shown in Table 1, ILLM model calculation results ("modeled input from the catchment") differ by no more than 2% from the values calculated based on the direct measurements on the Roshydromet observation network in the Irtysh River ("nutrient input in the river mouth based on Roshydromet data). According to modeling results, nutrient input for average flow can be estimated at 123,795 t N year^{-1} and 10,744 t P year^{-1}. The most significant part belongs to diffuse sources (69,388 t N year^{-1} and 3097 t P year^{-1}) due to the considerable impact of agriculture. Transboundary load at the mouth can amount 16,520 t N year^{-1} and 453 t P year^{-1}.

Table 2 presents an assessment of the various sources' contribution (%) to nutrient transport with Irtysh River in the Ust-Ishim (14.01.01) cross-section, as well as tributaries of the Om River (14.01.02), Ishim (14.01.05), Tobol (14.01.05) and Konda (14.01.06). The results are shown as a percentage of the total load at the mouth cross-section. The calculations were performed for an average water flow of 65.6 mm year^{-1} for the catchment area of the Irtysh River at the mouth, 36.7 mm year^{-1} for cross-section in Ust-Ishim, 22.1 mm year^{-1} for the Om River, 78.1 for Ishim River, and 170.5 for the Tobol River. Dominant values are highlighted in grey.

It can be concluded that the diffuse nutrient load prevails both in the entire Russian part of the Irtysh River's catchment area (56.0% nitrogen and 28.8% phosphorus of the total load from the catchment), and the Irtysh River in Ust-Ishim (57.5% nitrogen and 46.6% phosphorus), as well as Om River (84.8% nitrogen and 64.1% phosphorus), Ishim River (66.4% nitrogen) and Tobol River (65.1% nitrogen and 44.7% phosphorus).

Intensive agriculture production can be the reason for the dominance of the diffuse sources in southern parts of the catchment with high livestock density values. The minimum agricultural activity caused the predominance of the natural (background) load on the northernmost watercourse of the Konda River (95.7% nitrogen and 64.3% phosphorus of the total input from the catchment). The Russian part of the catchment of the Ishim River has the biggest share of the point phosphorus load (64.3%).

Table 2. Contribution of nutrient load components (%) to the total nutrient transport in the outlets from the studied catchments (hydrological units)

Hydrological unit	Transboundary load	Point sources	Natural background sources	Diffuse antropogenic sources
Total nitrogen				
14.01.01	32.8	0.0*	9.7	57.5
14.01.02	0.0	0.0	15.2	84.8
14.01.03	23.2	0.0	10.4	66.4
14.01.05	5.3	0.0	29.6	65.1
14.01.06	0.0	0.0	95.7	4.3
Total phosphorous				
14.01.01	19.1	8.8	16.4	46.6
14.01.02	0.0	0.7	17.8	64.1
14.01.03	8.0	58.1	5.5	19.4
14.01.05	1.2	21.0	20.9	44.7
14.01.06	0.0	0.7	64.3	20.8

* point sources input is less than 0.1%.

The significant impact of transboundary input can be found in the Ust-Ishim cross-section on the Irtysh River – 32.8% for nitrogen and 19.1% for phosphorus from the total input and at the outlet of the Ishim River – 23.2% for nitrogen, 8.0% for phosphorus. In general, the share of transboundary load in the Irtysh River nutrient transport at the outlet in the city Khanty-Mansiysk can amount 13.4% for nitrogen and 4.2% for phosphorus of total input from all sources for average water flow.

Quantification results of the current (for 2021) and potential (due to BAT introduction) nutrient loss to the river system from agriculture on the studied catchments within Russian borders, can be found in the Table 3.

Table 3. Actual (for 2021) and potential (due to BAT introduction) nutrient loss to the river system from agriculture on the studied catchments within Russian borders

Hydrological unit	N, t year^{-1} (2021)	N, t year^{-1} (BAT)	P, t year^{-1} (2021)	P, t year^{-1} (BAT)	ΔN, %	ΔP, %
14.01.01	37,673	31,941	1689	1520	15	10
14.01.02	12,097	10,688	701	652	12	7
14.01.03	4158	3195	209	174	23	17
14.01.05	56,296	38,794	2833	2124	31	25
14.01.06	37	26	2	2	30	0
14.01 – Russian part of the Irtysh River catchment	11,3925	87,449	5630	4636	23	18

* ΔN, %, ΔP, % – with regard to load reduction.

The greatest reduction of the agricultural nutrient load in the study areas due to BAT introduction can be achieved in the Russian part of the Tobol River catchment area (31% nitrogen and 25% phosphorus of the total agricultural load). The apparent reason for this is the maximum concentration of agricultural production within this unit. In general, BAT introduction on the whole Russian part of the Irtysh River catchment area can decrease nutrient loss by 23% for nitrogen and 18% for phosphorus.

Quantification of the nutrient input from all sources for the lowest cross-section and potential reduction due to BAT introduction presented in Table 4.

Table 4. Actual (for 2021) and potential (due to BAT introduction) nutrient input with Irtysh River and its tributaries on the Russian part of the catchment

Hydrological unit	N, t year^{-1} (2021)	N, t year^{-1} (BAT)	P, t year^{-1} (2021)	P, t year^{-1} (BAT)	ΔN, %	ΔP, %
14.01.01	38,782	35,371	1541	1401	9	9
14.01.02	7819	7041	406	391	10	4
14.01.03	3287	2779	492	412	15	16
14.01.05	49,299	38,929	5372	5126	21	5
14.01.06	10,008	10,000	1490	1490	0	0
14.01 – Russian part of the Irtysh River catchment	123,795	107,455	10,744	10,356	13	4

* ΔN, %, ΔP, % – with regard to load reduction.

Calculation results are significantly impacted by the agriculture load and other sources' input, as well as runoff volume, which determines the migration of nutrients to the river system (see equation (2)). The combination of these factors leads to the fact that the BAT introduction has the maximum impact on nitrogen load reduction in the Tobol River catchment area (21% of total nitrogen input) and phosphorus load reduction in the Russian part of the Ishim River catchment (16%). In general, BAT introduction on the whole Russian part of the Irtysh River catchment area can decrease total nutrient input by 13% for nitrogen and 4% for phosphorus.

An example of the possible BAT introduction effect is illustrated in Figure 4.

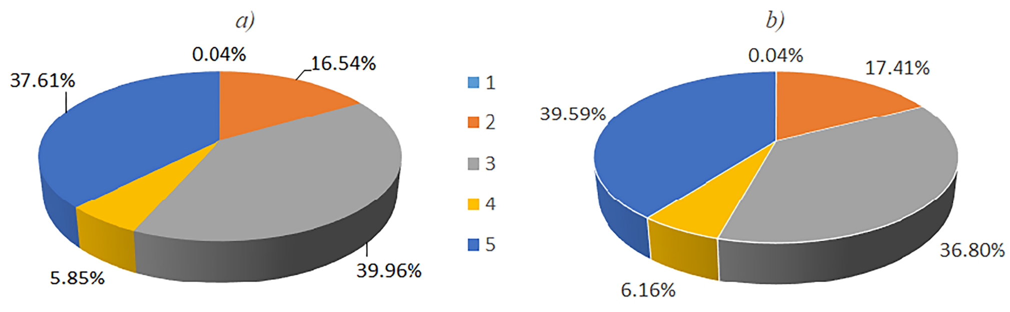

Figure 4. Source-apportionment of the Irtysh River total phosphorous (P_{tot}) input (outlet in the city of Khanty-Mansiysk) for average flow conditions for the current situation (a) and in case of BAT introduction (b): 1 – point sources input; 2 – atmospheric deposition; 3 – diffuse sources input; 4 – transboundary input; 5 – natural background load.

After the introduction of the best available techniques (BAT), decrease in agricultural phosphorus load on the water basin and its hydrographic network can achieve up to 18% annually for average flow conditions (Table 3). Diffuse sources have the highest influence on phosphorus input, accounting for 39.96% of the total phosphorus export value with the Irtysh River (Figure 4a). However, after introduction of the best available techniques, the contribution of diffuse pollution is reduced to 36.8%. At the same time, the natural component begins to dominate (Figure 4b). The overall reduction in phosphorus export with the Irtysh River due to introduction of the BAT is estimated to be approximately 4%.

5. Conclusions

Usually, the main recommendation regarding improving the ecological state of water bodies concerns lowering nutrient application rates during fertilization to reduce the risk of anthropogenic eutrophication. However, it is evident that in a situation of negative nutrient surplus, typical for agricultural lands in the Russian part of the Irtysh River's catchment area, lower fertilizers application rates lead to a decrease in agricultural production. At the same time, the main aim for farmers is to increase production volumes by seeking resources to raise fertilizer application rates. In such a situation, the BAT introduction is the only real mechanism for combining reducing the negative impact on the environment and increasing agricultural production with minimizing labor and energy costs. Mathematical modeling methods are a fundamental tool for quantifying the environmental impact of different components of agricultural production and defining the most convenient combination of measures to achieve environmental goals.

Modeling allows the identification of areas with the maximum risk of nutrient transport to the water bodies and planning measures to minimize it. The measures include not only BAT introduction, but also a number of technological and landscape solutions, for example, the creation of natural biofilters and special amelioration facilities, the use of special equipment for fertilizer application, etc.

It can be noted that the estimated nutrient load reduction from agriculture is hardly enough for the dramatic decrease of the Irtysh River nutrient input to the Ob River.

BAT introduction has the maximum impact on nitrogen load reduction in the Tobol River catchment area (21% of total nitrogen input) and phosphorus load reduction in the Russian part of the Ishim River catchment (16%). In general, BAT introduction on the whole Russian part of the Irtysh River catchment area can decrease total nutrient input by 13% for nitrogen and 4% for phosphorus.

According to the calculations, currently, diffuse (anthropogenic) pollution has the highest influence on phosphorus export with the Irtysh River at the Khanty-Mansiysk cross-section, accounting for 39.96% of the total export value. After the introduction of the BAT, there should be a reduction of 18% of agricultural phosphorus losses to water. The overall reduction in phosphorus export with the Irtysh River due to introduction of the BAT is estimated to be approximately 4%. The phosphorus load source apportionment will significantly change, with the contribution of diffuse pollution decreasing to 36.8%, and an increase shares of atmospheric load and transboundary transport, while the natural component begins to dominate.

However, the result confirms the possibility of decreasing Irtysh River nutrient transport due to BAT's introduction in agriculture to minimize labor and energy costs, which is an extremely important conclusion. At the same time, it is important that decision-makers have reliable estimates of the possible effects and perspectives of different environmental measures.

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References

Behrendt, H., and R. Dannowski (Eds.) (2005), *Nutrients and Heavy Metals in the Odra River System*, Schweizerbart Science Publishers, Stuttgart, Germany.

Briukhanov, A. Y., S. A. Kondratyev, N. S. Oblomkova, A. S. Ogluzdin, and I. A. Subbotin (2016), Calculation method of agricultural nutrient load on water bodies, *Technologies, machines and equipment for mechanised crop and livestock production*, pp. 175–186 (in Russian).

Briukhanov, A. Y., R. A. Uvarov, and I. A. Subbotin (2018), The Practice of best available technologies of poultry manure utilization in Leningrad region, *Poultry and Chicken Products*, *20*(3), 26–28, https://doi.org/10.30975/2073-4999-2018-20-3-26-28 (in Russian).

Buckwell, A., and E. Nadeu (2016), *Nutrient Recovery and Reuse (NRR) in European agriculture. A review of the issues,opportunities, and actions*, RISE Foundation, Brussels.

Chen, X., and M. Bechmann (2019), Nitrogen losses from two contrasting agricultural catchments in Norway, *Royal Society Open Science*, *6*(12), 190,490, https://doi.org/10.1098/rsos.190490.

GOST R 56828.15-2016 (2019), *National standard of the Russian Federation. Best Available Techniques. Terms and Definitions*, 50 pp., Standartinform, Moscow (in Russian).

HELCOM (2018), *Sources and pathways of nutrients to the Baltic Sea*, 153, Baltic Sea Environment Proceedings.

HELCOM (2022), Guidelines for the annual and periodical compilation and reporting of waterborne pollution inputs to the Baltic Sea (PLC-Water), https://doi.org/10.25607/OBP-1927.

Jacobsson, C. (Ed.) (2012), *Ecosystem Health and Sustainable Agriculture. Sustainable Agriculture*, 1, The Baltic University Programme, Uppsala University.

Jansson, T., H. E. Andersen, B. G. Gustafsson, B. Hasler, L. Höglind, and H. Choi (2019a), Baltic Sea eutrophication status is not improved by the first pillar of the European Union Common Agricultural Policy, *Regional Environmental Change*, *19*(8), 2465–2476, https://doi.org/10.1007/s10113-019-01559-8.

Jansson, T., H. E. Andersen, B. Hasler, L. Höglind, and B. G. Gustafsson (2019b), Can investments in manure technology reduce nutrient leakage to the Baltic Sea?, *Ambio*, *48*(11), 1264–1277, https://doi.org/10.1007/s13280-019-01251-5.

Kaur, K., A. Vassiljev, I. Annus, and P. Stålnacke (2017), Source apportionment of nitrogen in Estonian rivers, *Journal of Water Supply: Research and Technology - Aqua*, https://doi.org/10.2166/aqua.2017.036.

Kondratyev, S. A. (2007), *Formation of external load on water bodies: modeling problems*, Nauka, St. Petersburg (in Russian).

Kondratyev, S. A., and M. V. Shmakova (2019), *Mathematical modeling of mass transfer in the system: catchment - watercourse - water body*, Nestor-History, St. Petersburg (in Russian).

Lobchenko, Y. Y., N. Y. Lavrenko, I. P. Nichiporova, and A. V. Goncharov (2016), Dynamics of Organic and Biogenic Matter Content in the Ob River Basin Pyshma and Kunara Rivers, *Water sector of Russia: problems, technologies, management*, (2), 4–15, https://doi.org/10.35567/1999-4508-2016-2-1 (in Russian).

Nizhne-Ob Basin Water Administration (2014), *Scheme for the integrated use and protection of water bodies in the Irtysh River basin. Book 1. General characteristics of the river basin*, 303 pp. (in Russian).

Oenema, O., D. Oudendag, and G. L. Velthof (2007), Nutrient losses from manure management in the European Union, *Livestock Science*, *112*(3), 261–272, https://doi.org/10.1016/j.livsci.2007.09.007.

Pozdnyakov, S. R., A. Y. Bryukhanov, S. A. Kondratiev, N. V. Ignatieva, M. V. Shmakova, E. A. Minakova, A. M. Rasulova, N. S. Oblomkova, E. V. Vasiliev, and A. V. Terekhov (2020), Prospects of nutrients input reduction from river watersheds due to introduction of the best available technologies (BAT) for agricultural production (based on modeling results), *Water Resources*, *47*(5), 588–602, https://doi.org/10.31857/S0321059620050168 (in Russian).

Pozdnyakov, S. R., S. A. Kondratiev, E. A. Minakova, A. Y. Bryukhanov, and N. V. Ignatieva (2022), Results of assessing the dynamics and main trends in the content of chemical substances and the variability of the state of water bodies in the basin of the river irtysh in order to identify the pollution types, *resreport*, Barnaul (in Russian).

Sandström, S., M. N. Futter, K. Kyllmar, K. Bishop, D. W. O'Connell, and F. Djodjic (2020), Particulate phosphorus and suspended solids losses from small agricultural catchments: Links to stream and catchment characteristics, *Science of The Total Environment*, *711*, 134,616, https://doi.org/10.1016/j.scitotenv.2019.134616.

SP 33-101-2003 (2004), *The system of regulatory documents in construction. Code of rules for design and construction. Determination of Basic Design Hydrological Characteristics*, 73 pp., Gosstroy Rossii, Moscow (in Russian).

Svendsen, L. M. (Ed.) (2019), *Applied methodology for the PLC-6 assessment*, Baltic Marine Environment Protection Commission.

Tybirk, K., S. Luostarinen, L. Hamelin, L. Rodhe, S. Haneklaus, H. D. Poulsen, and A. L. S. Jensen (2013), *Sustainable Manure Management in the Baltic Sea Region*, Baltic Manure Business Opportunities.

Vtorova, A. I., M. V. Panina, and I. N. Likhodumova (2000), On the issue of monitoring the hydrological and hydrochemical regime of transboundary waters in the upper reaches of the Tobol river basin, in *Proceedings of the conference IVEP SB RAS*, pp. 27–34, IVEP SB RAS, Barnaul, Russia (in Russian).

Yakutina, O. P. (2014), Content of phosphorus in the surface runoff during snowmelt in the south of Western Siberia, *Problems of Agrochemistry and Ecology*, (1), 55–57 (in Russian).