Approaches to assessment of the total nitrogen and phosphorus inflow into the Neva Bay using the example of the Krasnenkaya River and the Dudergofskiy Channel

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Abstract. There is a necessity for the Baltic Sea environmental protection against toxic contamination and anthropogenic eutrophication. The protection proposes an annual evaluation of the total nitrogen and phosphorus income into the Neva Bay from St. Petersburg. The evaluation takes into account the substances, which inflow into the Neva Bay with water of the Neva River and its spill streams. However, an additional source of the substances is the substances inflow by runoff from watercourses entering Neva Bay. The watercourses do not have monitoring points. There is an additional source of the elements, which is the non-point dispersed outflow of the substances from the Neva Bay shore. The paper presents the evaluation methodology of the nitrogen and phosphorus outflow of catchment areas without monitoring points and the methodology verification result. The methodology uses data of analogous watersheds with close spatial structure, drainage network density, and average slope and so on. The methodology includes application of GIS-technologies and cluster analysis. The paper presents some results of the total nitrogen and phosphorus income into the Neva Bay with runoff of two small watercourses.

1 Introduction

The main ecological problem of the Baltic Sea consists in the anthropogenic eutrophication. The process is promoted by the sea isolation, significant volume of the river inflow, and high degree of the catchment area urbanization [1]. Superfluous income of the nitrogen and phosphorus lead to the eutrophication [2, 3]. A result of the process is increase of the blue-green algae biomass. The algae excretes dangerous toxins, which pervade within the food web, and can lead to toxication and even death of people. For example, in August 2022 there was tempestuous blooming of the blue-green algae in the Neva Bay. One of the species was *Microcystis aerugonisa* Kützing (according to the dada of

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Rosprirodnadzor. URL: https://rpn.gov.ru/, accessed 05.01.24). It is evident, that the countries occupying the most share of the Baltic Sea catchment area must have the most responsibility for the sea ecological safety. Total area of the Baltic Sea watershed is equal to 1740000 km^2. Bulk of the catchment area belongs Sweden – 440040 km^2 (26 %) and Russia 314800 km^2 (18%) [4]. Therefore Russia has greater accountability for the Baltic Sea environment maintenance.

Rivers of the south-west part of St. Petersburg are the most contaminated ones of the city. However, on the rivers there are no any points of state monitoring carried out by North-Western Department for Hydrometeorology and Environmental monitoring. We carried out natural researches of the rivers ecological state during 2021-2023 jointly learners of Palace of Child Youth Art «At the Voznesensky Bridge». There were evaluated average multiplicity factors of the fishery waters maximum permissible concentrations (MPC) exceedance (Table 1). The "P-PO4" column contents the phosphate phosphorus exceedance, "N-NH4" – one of the ammonium nitrogen, "N-NO2" – exceedance of the nitrite nitrogen, and "N-NO3" – exceedance of the nitrate nitrogen.

Table 1. Average multiplicity factors of the fishery waters maximum permissible concentrations exceedance of the nitrogen and phosphorus mineral forms during 2021-2023 in the researched water objects

No	Location (fig. 1)	$P\text{-}PO_4$	$N\text{-}NH_4$	$N\text{-}NO_2$	$N\text{-}NO_3$
	Fishery MPC, mg/l	0.05	0.5	0.02	40
1	The Novaya River (Narodnogo opolcheniya avenue bridge)	9.37	18.51	8.93	1.75
2	The Dachnaya River (Leni Golikova street bridge)	0.64	4.25	6.93	0.92
3	The Dachnaya River (the bridge west of Tankista Hrustickogo street)	0.40	3.96	1.25	2.76
4	The Dudergofskiy Channel, Geroev Av.	1.07	4.84	8.25	0.40
5	The Krasnenkaya River, Doblesti Street	0.75	6.59	6.65	0.18

It is evident, that the Novaya River is the most contaminated by the mineral forms of nitrogen and phosphorus watercourse. Here the nitrite ammonium concentration exceeds the fishery MPC more than in 18 times. Contents of the other mineral forms of the substances, except for the nitrate nitrogen are also exceed the MPC. Probably, the source is the dispersed outflow from the urbanized catchment areas. The watercourses in the south-west part of St. Petersburg are an integrated system. The Dudergofskiy Channel and the Krasnenkaya River enters the Neva Bay. The watercourses contamination leads to the anthropogenic eutrophication of the Neva Bay and the Baltic Sea as a whole.

The research goal consists in comparison of the evaluation results of the total nitrogen and phosphorus income into the Neva Bay with runoff of the Krasnenkaya River and the Dudergofskiy Channel on the base of natural researches and according to result of calculation using data of analogous watersheds.

2 Methodology

During 2022-2023, we sampled the Krasnenkaya River from the bridge at the intersection of Doblesti Street, and the Dudergofskiy Channel at the intersection of Geroev Avenue (fig. 1). The nitrogen and phosphorus mineral form concentrations were measured by colorimetric test with photometer "Expert-003" and by potentiometric analysis with potentiometer "Expert-001". The river discharges were measured once every three months by surface float method. The total nitrogen and phosphorus concentrations evaluation was carried out by the means of regression dependences [3].

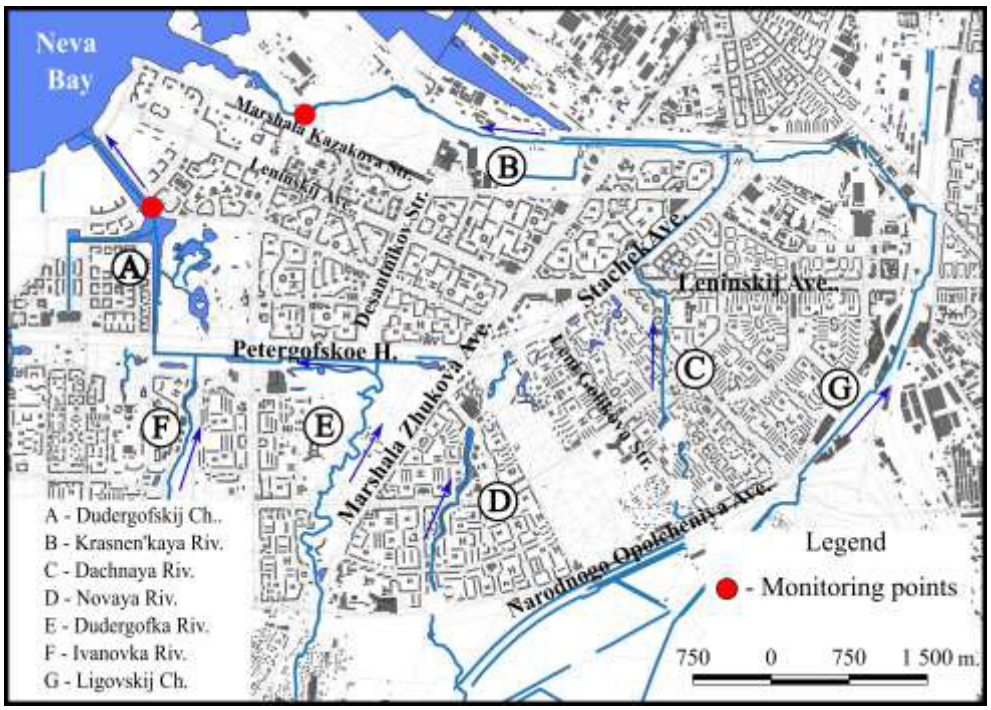

Fig. 1. Points of the Krasnenkaya River and the Dudergofskiy Channel sampling

Figure 2 presents spatial structure of the catchment areas.

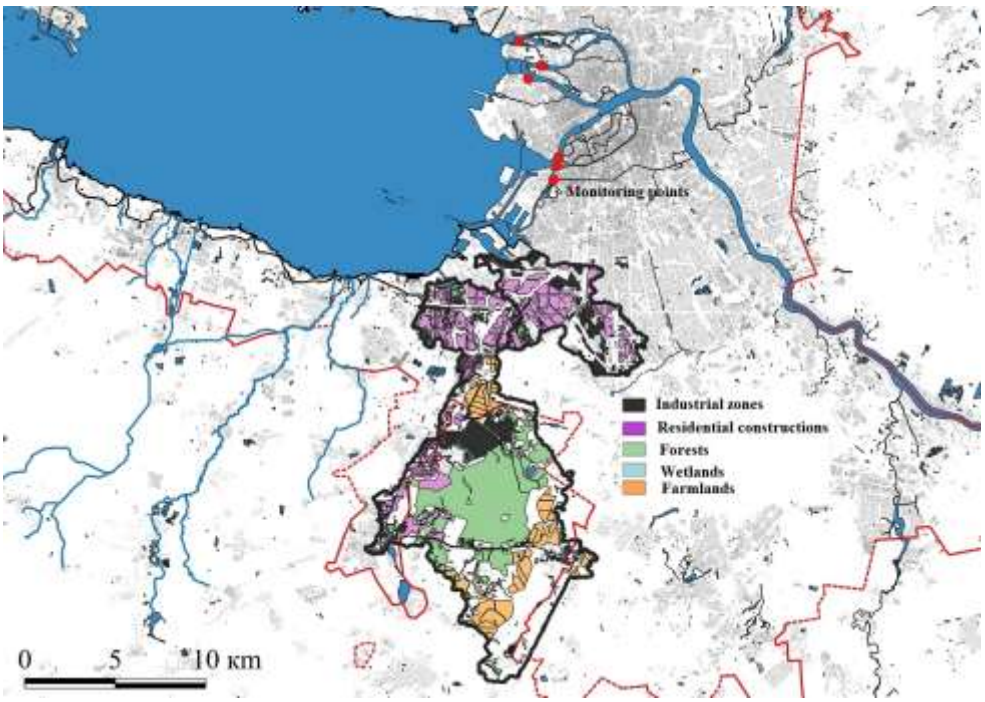

Fig. 2 Spatial structure of the watersheds

The total phosphorus or total nitrogen incomes with the watercourses stream runoff were calculated in accordance with the formula 1 [2]:

$$Q = 31.5\ C\ R \quad (1).$$

Here "Q" means the annual income of the total phosphorus or the total nitrogen with the watercourses stream runoff in metric tons, "C" – the average annual concentration of the total phosphorus or the total nitrogen in mg/l, "R" – the average annual stream runoff of the watercourses in m^3/sec.

In addition, we used for the calculations data of regular hydrochemical researches of State Unitary Enterprise (SUE) "Vodokanal of St. Petersburg". The SUE carry out the watercourses observations within industrial ecological control in connection with discharge of storm drainage into the watercourses.

The method of analogous catchment areas is used for evaluation of the nitrogen and phosphorus outflow from the watersheds without the monitoring points. The method consist of the following stages [5]:

1. Ascertainment of the watersheds boundaries by means of hydrological functions of GIS-technologies on the base of digital relief models;
2. The catchment areas spatial structure ascertainment. As the parameters of the watersheds there were used the amount of forests, the swamp percentage, the shares of industrial zones, residential constructions, farmland areas, and water objects areas;
3. The cluster analysis for choice of the analogous catchment areas with the monitoring points, which spatial structures are best of all close to the ones of the researched watersheds;
4. Evaluation of the total nitrogen and phosphorus outflow annual unit discharges of the analogous catchment areas on the base of the data of quarter-by-quarter hydrological and hydrochemical monitoring of North-Western Department for Hydrometeorology and Environmental Monitoring (NWDHEM).

The diurnal values of the total nitrogen and phosphorus concentrations were obtained by the NWDHEM data linear interpolation by means of specially worked out Mathcad programs.

There were carried out research of the catchment areas of the following watercourses and aquatic objects: the Privetnaya River, the Smolyachkov Stream, the Chyornaya River, the Ushkovskiy Stream, the Vosmoy Stream, the Bystraya River, the Zelenogorskiy Stream, the Shestoy Stream, the Tretiy Stream, the Sestroretskiy Razliv, the Chyornaya Lakhta River, the Lahtinskij Razliv, the Ligovskij Channel and the Krasnenkaya River, the Dudergofka River and the Dudergofskiy Channel, the Strelka Stream, the Kikenka River, the Shingarka and Strelka Rivers, the Troitskiy Stream, the Kristatelka River, the Karasta River watersheds. The objects enter the Neva Bay and the eastern part of the Finnish Gulf within the administrative border of St. Petersburg. However, there are no any monitoring points on the water objects. There were determined shore watersheds of the northern coast of the Finnish Gulf, and ones of the northern and southern coasts of the Neva Bay. The approximate evaluation of the total nitrogen and phosphorus income into the Neva Bay and the eastern part of the Finnish Gulf within the administrative border of St. Petersburg from all the watersheds was carried out on the base of data of the hydrological and hydrochemical monitoring on the analogous watercourses: the Mga, Tosna, Izhora, Oredezh, Vruda, and Volchya Rivers. By means of the cluster analysis there were determined the analogous watersheds with best of all close spatial structures to ones of the researched catchment areas. The unit discharges of the total nitrogen and phosphorus outflow from the analogous watersheds were used for the calculation of the substances outflow from the researched watersheds. Figures 3 and 4 demonstrate generalized annual dynamics of the nitrogen and phosphorus concentrations (mg/l) in mineral compounds in the analogous rivers.

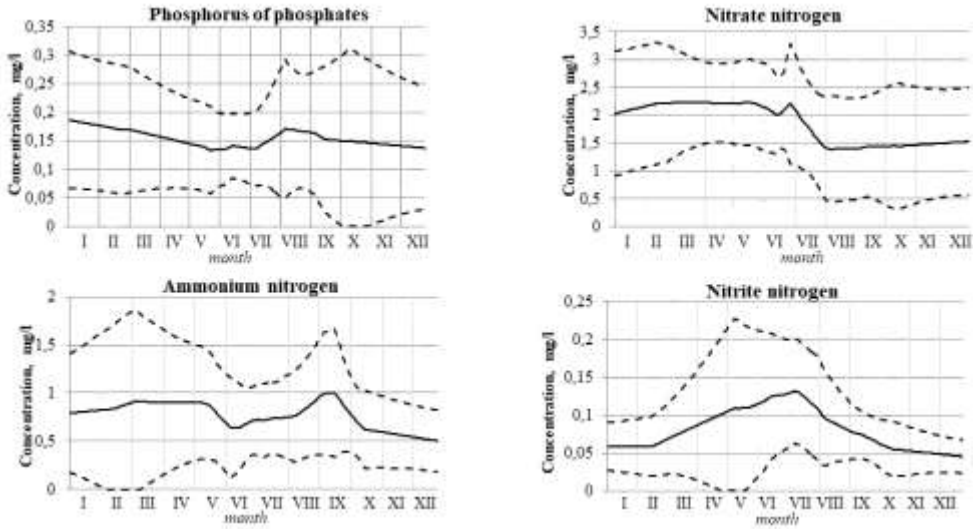

Fig. 3 Generalized annual dynamics of the nitrogen and phosphorus (mg/l) in mineral compounds in the Izhora River (─ average value, ----- borders of the confidential interval)

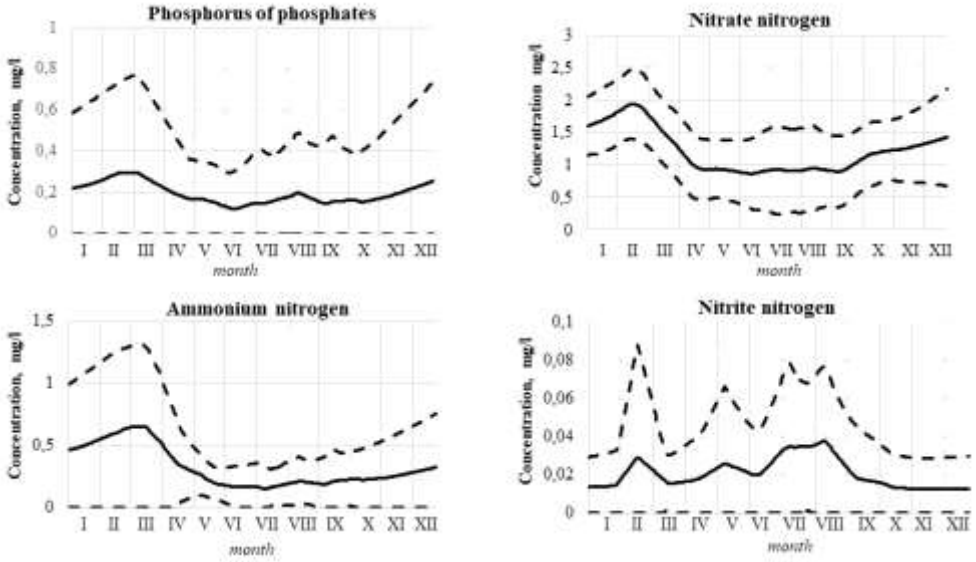

Fig. 4 Generalized annual dynamics of the nitrogen and phosphorus (mg/l) in mineral compounds in the Vruda, Mga, Oredezh, and Tosna Rivers

3 Results and discussion

According to the cluster analysis results the Izhora River watershed was determined as the analogous one for the catchment areas of the Krasnenkaya River and the Dudergofskiy Channel. Table 2 demonstrates the watersheds spatial structures.

Table 2. Spatial structure of the catchment areas: 1 – forests, 2 – wetlands, 3 – farmland areas, 4 – residential constructions, 5 – industrial zones, 6 – lakes and reservoirs, 7 – drainage network density (km-1), 8 – incline (°)

Watersheds	Area, km^2	Share of the total watershed area, %							
		1	2	3	4	5	6	7	8
Ligovskij Channel and Krasnenkaya River	31.6	2.6	<0.1	0.0	27.9	14.6	0.624	0.009	0.437
Dudergofka River and Dudergofskiy Channel	126.7	27.7	0.1	10.0	10.7	4.7	1.119	0.010	3,002

According to our calculations, average annual unit discharge of the total nitrogen outflow from the Izhora River watershed is equal to 2416.0 kgN/km2, and one of the total phosphorus – 141.4 kgP/km2. The area of the Krasnenkaya River together with the Ligovskij Channel watershed is equal to 31.6 km2, and area of the Dudergofskiy Channel together with the Dudergofka River – 126.7 km2. Multiplication of the analogous watershed annual unit discharges at the researched watersheds areas results in average annual values of the substances outflow from the researched catchment areas into the Neva Bay. The values of the Krasnenkaya River watershed are equal to 76.345 metric tons of the total nitrogen per year and 4.468 metric tons of the total phosphorus per year, the analogous values of the Dudergofskiy Channel catchment area are equal to 306.000 metric tons of the total nitrogen per year and 17.915 metric tons of the total phosphorus per year. Results of our evaluation of the annual income of the total nitrogen and total phosphorus into the Neva Bay with stream flows of the Krasnenkaya River and the Dudergofskiy Channel on the base of natural researches during 2019-2023 and the calculations with using of the analogous watershed data are presented in Table 3.

Average annual values of the incomes into the Neva Bay with stream flows of the Neva River and its spill streams during 1979-2022 are equal to 55092 metric tons per year of the total nitrogen and 1672 metric tons per year of the total phosphorus [2, 6]. Comparison of the total nitrogen and phosphorus incomes with stream flows of the Krasnenkaya River and the Dudergofskiy Channel (Table 3) with the total nitrogen and phosphorus income with stream flows of the Neva River and its spill streams demonstrates that the incomes with stream flows of the Krasnenkaya River and the Dudergofskiy Channel amounts about 1% of the total nitrogen income and about 2.5 % of the total phosphorus income with stream flows of the Neva River and its spill streams.

It is evident that the values of the total nitrogen and phosphorus incomes evaluation by means of the analogous watersheds method are smaller the values obtained on the base of natural researches. Probably, source of the difference consists in short duration of the natural researches. Other possible cause of the difference consists in less urbanization of the Izhora River watershed compared with catchment areas of the Krasnenkaya River and the Dudergofskiy Channel.

4 Conclusions

At the research, there were used data of industrial ecological control of the Krasnenkaya River and the Dudergofskiy Channel water chemical constitution. The control was carried out during 2019-2021 by SUE “Vodokanal of St. Petersburg”.

Table 3. Income of the total nitrogen and total phosphorus into the Neva Bay with stream flows of the Krasnenkaya River and the Dudergofskiy Channel, metric tons/year, 1 – results of the calculations on the base of SUE "Vodokanal of St. Petersburg" data, 2 – results of the calculations on the base of our natural researches data

Watercourse	**Substance**	**2019[1]**	**2020[1]**	**2021[1]**	**2022[2]**	**2023[2]**	**By natural data**	**By analogous watershed data**
Krasnenkaya Riv.	Total P	5.207	19.337	4.336	2.283	1.181	6.469	4.468
	Total N	41.421	148.976	127.007	161.737	94.675	114.763	76.345
Dudergofskiy Ch.	Total P	44.795	73.600	18.514	37.297	No data	43.552	17.915
	Total N	1127.940	1660.451	669.553	2235.203	747.276	1288.085	306.000

During 2022-2023 we sampled the watercourses mouths, measured the river discharges, carried out the hydrochemical analysis. On the base of the data there were calculated the total nitrogen and phosphorus incomes into the Neva Bay with stream flows of the watercourses. In addition, evaluation of the incomes was carried out by calculation on the base of the total nitrogen and phosphorus outflow annual unit discharges of the Izhora River catchment area. The unit discharges were evaluated because of our research. Similarity of the Izhora River watershed spatial characteristics and ones of the Krasnenkaya River and the Dudergofskiy Channel catchment areas was ascertained by means of the cluster analysis. It is established that unaccounted by North-Western Department for Hydrometeorology and Environmental Monitoring incomes of the total nitrogen and phosphorus into the Neva Bay with stream flows of the Krasnenkaya River and the Dudergofskiy Channel are equal to merely around 1% of the total nitrogen income with stream flow of the Neva River and its spill streams, and around 2.5% of the analogous income of the total phosphorus.

There was carried out verification of the methodology for the substances unit discharge evaluation on the base of the analogous catchment areas data. The verification consists in comparison of the values obtained on the base of the natural research results and ones resulted from the calculation using the unit discharges of the analogous watersheds. The comparison result points at possibility of the analogous watersheds method usage for approximate evaluation of the total nitrogen and phosphorus outflow of the catchment areas, which are not accounted at evaluation of the substances income into the Neva Bay and the eastern part of the Finnish Gulf. In this particular case, the income values determined on the base of the natural research are more than the values obtained by means of the analogous watersheds methodology. Probably, it should be better to apply for the calculations the unit discharges of more urbanized catchment areas, for example, ones of

the Volkovka River and the Okhta River downstream. The problem of the incomplete evaluation of the total nitrogen and phosphorus income into the Neva Bay and the eastern part of the Finnish Gulf is still actual.

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