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Background Phosphorus Concentrations in the Unmonitored and Partially Monitored Rivers of the Baltic Sea Basin

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Abstract—The evaluation of the background flow modules of total (unfiltered) phosphorus catchment areas a number of uncontrolled and partially controlled drainage basin of the Baltic Sea and the background concentrations of total phosphorus in the waters of the rivers under consideration.

Keywords: Eutrophication, biogenic elements, background concentrations, runoff modules.

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The modern development of the Baltic Sea as part of the geographical environment is determined by the fact that its basin is among the most densely populated and highly developed areas of the world with a high concentration of industry and intensive agriculture and forestry. Intensified exploitation of the Baltic Sea as a source of bioresources, the receiver of waste water, transportation highway, recreational area, as a source of minerals.

Anthropogenic eutrophication has now become the central problem of the Baltic Sea [2], the main signs of eutrophication in the Baltic Sea have been identified earlier than in other sea areas. A number of reasons contributes to rapid eutrophication of the Baltic Sea, of which the most important are the following two. First, it is relatively small sea, surrounded by economically highly developed countries, its catchment area is 1720270 km^2 and almost 4 times exceeds the area of the sea [18]. Annual river discharge is more than 2% of the entire sea volume [3]. Despite some water-protective measures, Baltic Sea receives a significant amount of organic contaminants and biogenic nutrients. The second reason that promotes eutrophication is that Baltic Sea is semi-enclosed body of water. The slow water exchange with the North Sea leads to the fact that organic matter, both allochthonous and autochthonous, and nutrient salts accumulate mostly in the Baltic sea.

One of the most important factors in the development of this process is the biogenic nutrient load to the drainage basin of the sea, which has two components: natural and anthropogenic. Extremely important in the balance of biogenic elements in the sea, in the matter of migration flows to differentiate and evaluate the role of the anthropogenic component. The main source of nutrients of natural and anthropogenic origin in the Baltic Sea is river runoff, which, in general, is characteristic to the humid areas, and therefore one needs not only to quantify the sources of eutrophying substances on the drainage basin, but to differentiate background (natural) and anthropogenic components of nutrient runoff within closing gauges. Particular attention should be paid to the fact that, as a rule, the background nutrient runoff is comparable with anthropogenic, and in some cases even exceeds it. This fact suggests the need to consider the background flow in the quota of nutrient loading to the receiving water bodies. However, the problem of determining the ratio between the quantities of natural and anthropogenic nutrient runoff is very complex and still remains controversial.

Earlier, we proposed and tested methodology for assessing the background component of biogenic runoff from monitored rivers in the Baltic Sea area, for which there are data series of hydrochemical and hydrological observations [9–13]. However, for the evaluation of the background concentrations of nutrients in uncontrolled or partially controlled rivers it is necessary to develop special techniques.

In view of the above, the aim of this study was to estimate background levels of total (unfiltered) phosphorus in the waters of uncontrolled and partially controlled rivers of the Baltic Sea drainage basin.

First, modules of background flow of total phosphorus in water catchment areas of a number of rivers in the Baltic Sea basin have been evaluated. Flow module is an universal characteristic, regardless of the order and the water content of the river, and serves as a measure of the intensity of anthropogenic impact on the catchment area.

The basis of our technique was developed on the idea that a natural component of the phosphorus load to the reservoir from its catchment area depends on the primary production of terrestrial ecosystems controlled by environmental factors: temperature, amount of precipitation, and evaporation [4, 7, 20, 21]. Environmental factors affecting the production processes in waters and on land, closely linked to the geographical zoning, which can be considered as a factor, integrating the influence of edaphic and climatic conditions on the productivity of aquatic ecosystems [1]. On the basis of works [1, 7] we proposed an empirical relationship between the modulus of the background flow of total phosphorus from the catchment area [$M(P_{\text{total}})^{\text{bckgd}}$, kg P km^{-2} year^{-1}] and geographic latitude (φ, ° N. L.) for the range of latitudes from 10° N to 70° N [10, 11, 16]:

$$M(P_{\text{total}})^{\text{bckgd}} = 221 - 52.3\ln \varphi. \quad (1)$$

The rationale for the legality of this approach was the results of comparing the values of the background flow of total phosphorus to the river Neva and her arms and modules of background flow of total phosphorus from the Neva drainage basin, estimated using various approaches:

(1) The method of empirical background coefficients, proposed by M.P. Maksimova [8] and modified by us for the Neva river with her arms [10, 12–14];

(2) The method developed by us [10, 13, 15, 16] on the basis of the concentration dependance of polluting substances in the dissolved state on the inverse values of the river flow, proposed by D. Deyvis and D. Tsobrist [17];

(3) The above-described technique based on the Eq. (1) [11, 16].

The results of our calculations were also compared with the values obtained by S.A. Kondrat’ev by mathematical modeling [5].

We have shown that for the calculations of values of the background flow of total phosphorus from the catchment areas of rivers with small drainage basin in the first approximation can be used the value of the latitude at the midpoint of the catchment area (φ_{av}, °N). Calculation of the background P_{total} from a river’s catchment area, which occupies the latitude of 2° N, (with a mean of geographic latitude 59° N), which is about 222 km, leads in this case to a relative error of slightly more than 1% [10]. Method of calculating the values of background flow of total phosphorus for the rivers with large catchment areas is given in details in [9].

Secondly, we have determined the values of the background flow of phosphorus from the catchment areas of the rivers under consideration [$Q(P_{\text{gross}})^{\text{bckgd}}$, t year^{-1}] without retention of biogenic elements by hydrographic network of their catchment area:

$$Q(P_{\text{total}})^{\text{bckgd}} = \frac{M(P_{\text{total}})^{\text{bckgd}}}{1000} \times S, \quad (2)$$

where S is catchment area, km^2.

On the basis of these results annual average background concentrations of phosphorus [$C_{\text{aa}}(P_{\text{total}})^{\text{bckgr}}$, μg dm^{-3}] have been calculated, taking into account the retention by their drainage basin and drainage network:

$$C_{\text{aa}}(P_{\text{total}})^{\text{bckgd}} = \frac{R_t(P_{\text{gross}})Q(P_{\text{total}})^{\text{bckgd}}}{0.0315C_{\text{aa}}}, \quad (3)$$

where C_{aa} is the average annual water consumption in m^3 s^{-1}, R_t is phosphorus runoff coefficients, calculated according to [6].

Results of calculations are given in the table.

Obtained calculated values of the background flow modules and background concentrations of phosphorus are consistent with the official data on biogenic nutrients intake to the Baltic Sea from the catchment areas of the HELCOM (Helsinki Commission for the Protection of the Marine Environment of the Baltic Sea) participating countries [18, 19].

Thus, the proposed approach allows to perform *a priori* estimate of background concentrations of phosphorus in rivers without need for time-consuming procedures for the collection and processing of large

Background flow modulus and total phosphorus concentarations for some rivers of Baltic sea basin

River	S, km^2	R_{aa}, m^3 s^{-1}	$M(P_{total})^{bckgd}$, kg P km^{-2} year^{-1}	$Q(P_{total})^{bckgd}$, t year^{-1}	R_t	$C_{aa}(P_{total})^{bckgd}$, μg dm^{-3}
Finnish gulf rivers						
Vaaliman-joki (Kokselan-joki)	295	3.1	6.43	1.90	0.69	14
Ser’ga (Urpala-joki)	94.5	1.02	6.39	0.60	0.70	13
Peschanka (Santa-joki, Eolkka-joki)	200	2.1	6.37	1.27	0.69	13
Vila-joki (Velikaya)	161	1.7	6.33	1.02	0.70	13
Chulkovka (Kisi-joki, Nisa-joki)	72	0.78	6.29	0.45	0.71	13
Polevaya (Terva-joki)	160	1.74	6.28	1.00	0.71	13
Seleznevka (Yuksepan-joki)	623	6.7	5.69	3.55	0.70	12
Cherkasovka (Ilya-joki)	116	1.25	6.07	0.70	0.70	13
Drema (Korpelan-joki)	45.7	0.5	6.35	0.29	0.71	13
Matrosovka (Sommen-joki)	55.2	0.6	6.36	0.35	0.71	13
Gorokhovka (Alexandrovka, Rokhkolan-joki)	731	7.9	6.43	4.70	0.71	13
Vika-joki	42.5	0.46	6.60	0.28	0.71	14
Lososinka stream	56.2	0.6	6.67	0.37	0.70	14
Privetnaya (Inon-joki, Ozernaya, Mesterjarven-joki)	70	0.8	6.72	0.47	0.73	14
Chernaya (Gladyshevka, Vammel sun-joki)	668	7.2	6.65	4.44	0.70	14
Sestra	399	4.3	6.67	2.66	0.70	14
Chernaya	126	1.4	6.74	0.85	0.72	14
Kamenka	134	1.5	6.85	0.92	0.72	14
Dudergofka	120	0.69	7.07	0.85	0.41	16
Kikenka (Kekenka)	68	0.29	7.00	0.48	0.28	15
Strelka	155	2.45	7.15	1.11	0.83	12
Shingarka	121	1.3	7.08	0.86	0.70	15
Karasta	55.8	0.62	6.96	0.39	0.72	14
Chernaya rechka (Sapa-oja)	96.2	0.7	7.25	0.70	0.53	17
Lebyaz’ya	101	0.74	6.93	0.70	0.53	16
Kovashi	612	4.45	7.03	4.30	0.53	16
Voronka	286	2.08	7.07	2.02	0.53	16
Sista (Teplushka)	672	7.2	7.15	4.81	0.70	15
Lovkolovsky brook	50	0.36	7.06	0.35	0.52	16
Khabolovka (Khobalovka)	330	3.53	7.17	2.37	0.70	15
Luzhitsa	50	0.36	7.20	0.36	0.52	17

Table. (Contd.)

River	S, km^2	R_{aa}, m^3 s^{-1}	$M(P_{total})^{bckgd}$, kg P km^{-2} year^{-1}	$Q(P_{total})^{bckgd}$, t year^{-1}	R_t	$C_{aa}(P_{total})^{bckgd}$, μg dm^{-3}
Curonian gulf rivers						
Dal'nyaya (Akminge)	38.5	0.29	11.21	0.43	0.54	26
Razliv (Karkelnfluss)	64.8	0.49	11.25	0.73	0.55	26
Uzkaya (Rungel)	23.3	0.18	11.26	0.26	0.56	26
Rybnaya (Loyerfluss)	68	0.52	11.29	0.77	0.55	26
Promyslovaya-Prudnyi kanal (Gribe - Klein Prudimm)	70.7	0.54	11.25	0.80	0.55	26
Nemonin (Nemonina, Schalteck)	1380	9.5	11.44	15.8	0.50	26
Deima (Daime)	100	0.76	11.65	1.17	0.55	27
Vostochnyi kanal-Ovrazka	59.4	0.45	11.57	0.69	0.55	27
Zapadnyi kanal-Slavnaya	170	1.29	11.63	1.98	0.55	27
Ol'khovka	43.7	0.33	11.48	0.50	0.55	26
Malaya Moryanka	36.6	0.28	11.49	0.42	0.55	26
Bol'shaya Moryanka	65.1	0.49	11.48	0.75	0.54	26
Kalinovka	15.4	0.12	11.53	0.18	0.56	26
Lobovka	37	0.28	11.51	0.43	0.55	26
Kurovka (Dariner beeck)	60.6	0.46	11.52	0.70	0.55	26
Trostyanka (Bledauer beeck)	123	0.93	11.83	1.45	0.55	27
Visla gulf rivers						
Graevka (Laukne-Greibauer Moen-fluss)	137	1.04	11.65	1.60	0.55	27
Kaliningrad (Koenigsberg) obvodnoi kanal	59	0.45	11.55	0.68	0.55	26
Nel'ma (Vorkenefluss)	167	1.27	11.61	1.94	0.55	27
Primorskaya (Germauer Muelenfluss)	126	0.96	11.63	1.46	0.55	27
Prokhladnaya (Frisching)	1170	8.9	11.84	13.9	0.55	27
Mamonovka (Benau)	311	2.6	11.94	3.71	0.59	27

data sets, characterizing their drainage basins catchment areas.

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