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HIGHER AQUATIC PLANTS

Use of Macrophytes in Assessing the Ecological Status of Small River (by the Example of the Okhta River, St. Petersburg)

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Abstract—Hydrochemical and hydrobiological characteristics have been studied at 13 sites in the Okhta River within the precincts of St. Petersburg in 2010. The Water Pollution Index (WPI), calculated according to hydrochemical parameters, characterizes the river water quality as "very polluted" to "extremely polluted." According to the Pantle–Buck–Sládeček Saprobity Index, obtained on the basis of macrozoobenthos characteristics, polysaprobic and α-mesosaprobic zones can be distinguished in the watercourse. The species richness of river macrophytes is low (18 species). The Macrophyte Water Quality Index makes it possible to assess water quality in the range from "polluted" to "very polluted" water. Macrophyte trophic indexes *MTR*, *IBMR* and *TIM* indicate a high trophy level in the watercourse sites. Based on the analysis of hydrochemical materials and the data on macrozoobenthos and macrophytes, the general tendency is similar: deterioration of water quality downstream. Macrophyte characteristics reflect changes in hydrochemical parameters downstream the river course. A strong correlation ($r = -0.76$) is found between the Macrophyte Water Quality Index and WPI. The possibility of using the data on macrophytes in small rivers for assessing water quality is demonstrated.

Keywords: small river, bioindication, quality assessment, ecological status, macrophytes, trophic indexes

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INTRODUCTION

The lack of indexes based on macrophyte development in water objects practically excludes this group of organisms from a multicriteria (integral) ecological assessment of aquatic ecosystems. Such an assessment should include a parametric assessment of the chemical and biological composition and physical properties of a water object, which determine the stable functioning of particular communities of living organisms in it and the preservation of a certain type of ecological succession [7].

A multicriteria assessment requires the construction of an integral parameter using a set of assessment criteria. This set should include the criteria of the state of abiotic environment and biota; here it is necessary for all parameters to be sufficient for a description of the quality (state) of the system under consideration [7]. When assessing the ecological state of small rivers, it is quite reasonable to use the parameters associated with the development of macrophytes, often the main primary producers in watercourses [26, 34].

Methods of monitoring of small rivers based on macrophyte vegetation have been applied and developed by a number of researchers [4, 9, 18, 24, 25, 28, 35, etc.]. Most of these studies are based on a determination of the indicator value of a particular plant species. Nevertheless, this generally successful approach imposes limitations on the assessment possibility in the absence of indicators, e.g., in rivers in urbanized territories. The paper demonstrates the application of this method based on the metrics of diversity, richness, and abundance of species, which does not require the determination of an indicator value of certain taxa. Such an approach may be successfully achieved upon the careful selection of stations for field studies despite the necessity of analyzing the sites in a watercourse similar in length, morphology, and shading degree [33].

The so-called macrophyte-based methods of assessing the trophic status of waterbodies have been widely applied [23, 27, 30]. Indexes calculated using these methods reflect the concentration of biogenic elements in the river water. Such dependences are shown, for example, for southern European rivers [31]. The application of these methods for watercourses in Russia has not been previously considered, except for some publications [8].

The aim of this work is to demonstrate the possibility of using the data on macrophytes in small rivers (by

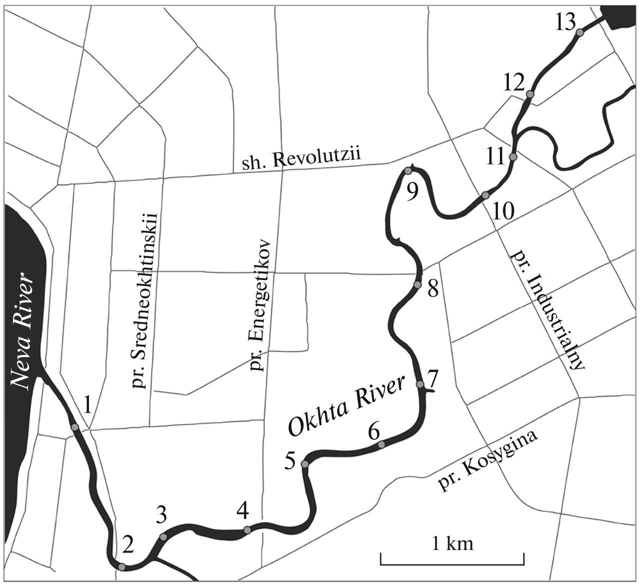

Fig. 1. Scheme of location of stations (1–13) of the hydrobiological survey in the Okhta River.

the example of the Okhta River) for assessing their water quality.

MATERIALS AND METHODS

The Okhta River is the largest right tributary of the Neva River within the city limits of St. Petersburg [5]. It originates in the area of Lembolovo Heights on the Karelian Isthmus. The length of the Okhta is 90 km and it flows 9 km through the city area; its drainage basin is 768 km^2. The dam of the Okhta Reservoir regulates the river flow within the city limits; therefore, the regime of the level and water discharge depends on the operation of hydrotechnical constructions. In addition, changes in the water level in the Neva River affect the water level in the lower part of the Okhta River.

Pollutants in wastewater discharges and from nonpoint sources impact the hydrochemical regime. There are embankments in some river sections; >10 road, railway bridges, and footbridges cross the river.

According to the data obtained by the Northwest Territorial Department for Hydrometeorology and Environmental Monitoring, Russian Federal Service for Hydrometeorology and Environmental Monitoring (Rosgydromet), at the monitoring site of the surface water state (Okhta River, Shaumyan bridge), in 2010 the Okhta River was the most polluted river in the Baltic geographical region. According to BOD_5 and COD values and the complex of pollutants, its water was characterized as "very polluted," and copper, iron, zinc, manganese, and nitrite nitrogen were the main pollutants [12, 16].

The work presents the results of field studies conducted in the lower reaches of the Okhta River by the staff and students of the Department of Applied Ecology, Russian State Hydrometeorological University (RSHMU). The surveys were conducted at 13 stations (Fig. 1) in the part of the river within the city limits in July 2010. Characteristics of macrophytes were described for each station according to the methods presented in the works [3, 11]. The surveys were conducted in a river section with a length of ~50 m, "from bank to bank," that reaches ~1500 m^2 at an average width of the river of ~50 m. A visual scheme of overgrowing of the river section was made on the site, the degree of its overgrowing was recorded in percent, the primary species identification of plants was made, the abundance was estimated using the point scale according to the projective cover of the species, herbarium samples were collected, and photos of the site were made for the further specification of overgrowing characteristics. Samples of water and bottom sediments were simultaneously collected at each station for a determination of hydrochemical parameters and characteristics of macrozoobenthos in the river.

Hydrochemical parameters (pH, alkalinity, hardness, chlorides, calcium, magnesium, BOD_5, dissolved oxygen, permanganate index, the total content of iron, concentrations of nitrites, phosphates, manganese, and phenols) were determined in the Laboratory of Environmental Chemistry, RSHMU. The taxonomic identification of benthic organisms and calculation of biotic indexes were made by A.Yu. Kulichenko.

The Water Pollution Index (WPI) was calculated using the materials of one survey for an assessment of the water quality based on hydrochemical parameters according to the method [14]. The obtained index was considered to be a reconnaissance index of water pollution.

Ecological groups of aquatic plants are given according to V.G. Papchenkov's classification [17]. The Shannon index was used for a quantitative assessment of aquatic plant diversity in different parts of the river. The trophy level of the river was determined using the following indexes: *MTR*, Mean Trophic Rank [27]; *IBMR,* Macrophyte Biological Index for Rivers [23]; and *TIM*, the Trophic Index of Macrophytes [30]. For the application of macrophyte characteristics in assessing water quality in small rivers, we used our point scale–index method, which included the following parameters: the index of species diversity at a station, the number of true aquatic plants, and the total abundance of macrophytes (Table 1).

Using the data on H_{1-5}, N_1 and ΣA, we sequentially determined the corresponding point of each characteristic for a particular station in the watercourse. The *Sm* index was calculated using the sum of three obtained points. Four classes of water quality were distinguished: very polluted (*Sm* from 3 to 4), polluted

Table 1. Assessment of water quality in small rivers using macrophyte characteristics

Parameter	Points			
	1	2	3	4
H_{1-5}	<2.0	2.0–3.9	4.0–4.9	≥5.0
N_1	0	1	2	≥3
ΣA	<30	30–39	40–49	≥50

H_{1-5} is the index of species diversity of all macrophytes (ecogroups 1–5); N_1 is the number of hydrophytes (ecogroup 1) and ΣA is the total abundance of macrophytes.

(from 5 to 7), moderately polluted (from 8 to 10), and clean (from 11 to 12).

RESULTS

During the surveyed period, water in the Okhta River was characterized as soft in terms of hardness with neutral pH (Table 2). Since the concentrations of phenols, chlorides, calcium, magnesium, and alkalinity values were within the permissible limits, they are not presented in Table 2. Values of five hydrochemical parameters (BOD_5, permanganate index, the total content of iron, and concentrations of nitrites and phosphates) were high. In addition, the concentration of dissolved oxygen in water was always less than the norm; it decreased from station 13 to the mouth, reaching the maximum value at station 2.

The spatial dynamics of the water pollution increased towards the mouth. The highest pollution level was recorded in the lower part of the surveyed river section. Thus, the maximum content of nitrites and total iron was recorded at station 5; high concentrations of phosphates were recorded at station 6 and hypoxia was observed in the section from station 2 to station 4 and at station 6 in the surface water layer (Table 2)

The near-mouth part of the river (station 1) is less polluted than the preceding (upstream) stations. The minimum values of BOD_5, permanganate index, total iron, and nitrites were recorded at station 1. This can be explained by the effect of the Neva River waters, which dilute extremely polluted water masses of the Okhta River. The described features are confirmed by calculated values of the WPI (Table 3).

Characteristics of macrozoobenthos communities are used for an assessment of the ecological status of watercourses. The bottom communities in the Okhta River and assessment of water quality using these communities have been analyzed in the works [1, 2, 6, 13]. The data on zoobenthos were obtained at 13 stations in the river during the year under study.

There were considerable differences in the distribution of organisms among stations (Table 4). Bottom animals were absent in samples collected at eight stations. At station 13, it can be the result of the water release through the dam of the Okhta Reservoir, but at the other sites (stations 1–4, 7, and 8) the absence of benthic organisms can be, mainly, explained by the pollution of water and bottom sediments. High values of macrozoobenthos biomass were recorded at stations 9 and 10, where bivalves and gastropods made the main contribution to biomass. Nevertheless, a considerable proportion of oligochaetes of the family Tubificidae (*Limnodrilus hoffmeisteri* Claparède, 1862, *Tubifex tubifex* (Müller, 1774)) indicate the pollution of this river section with organic matter. Bottom animals at stations 5 and 6 are represented only by oligochaetes.

According to the Pantle–Buck–Sládeček Saprobity Index, waters in the Okhta River are characterized as polysaprobic and α-mesosaprobic (Table 5). Saprobiological conditions tend to deteriorate downstream the river.

During the year of studies, macrophytes in the Okhta River were represented by 18 species, 10 of which grow in the channel (Table 6). The most wide-

Table 2. Hydrochemical characteristic of the surveyed stations in the Okhta River

Parameter	Station												
	1	2	3	4	5	6	7	8	9	10	11	12	13
pH	7.14	7.19	7.15	7.18	7.24	7.26	7.33	7.40	7.42	7.28	7.35	7.30	7.44
Hardness, meq/dm^3	2.7	2.7	2.6	2.7	3.5	3.6	3.5	3.4	1.8	3.1	3.0	3.1	3.0
Oxygen, mg/dm^3	2.21	1.01	1.49	1.39	2.32	1.81	2.50	2.88	4.14	3.11	3.30	3.67	4.90
BOD_5, mg/dm^3	3.48	4.39	4.29	4.94	5.15	5.35	4.27	4.35	4.77	4.90	3.97	4.90	6.20
Permanganate index, mg/dm^3	18.1	19.7	19.4	19.4	20.2	20.2	20.5	20.3	20.0	18.6	19.9	20.7	20.5
Total iron, mg/dm^3	2.0	2.6	3.1	2.9	8.0	2.9	4.0	3.3	2.8	3.2	3.1	2.4	2.2
Manganese, mg/dm^3	0.34	–	0.39	–	–	0.28	–	0.37	–	–	0.35	–	0.29
Nitrites, mg/dm^3	0.69	0.83	0.81	0.87	1.25	1.05	1.19	1.09	0.87	0.93	0.85	0.75	1.05
Phosphates, mg/dm^3	1.06	1.38	1.49	1.52	1.74	3.83	2.10	1.20	0.96	0.99	0.96	0.92	1.06

Table 3. WPI at the surveyed stations in the Okhta River

Parameter	Stations												
	1	2	3	4	5	6	7	8	9	10	11	12	13
WPI	9.1	15.8	13.9	14.2	20.4	14.7	13.7	11.4	8.4	9.4	8.9	7.5	7.0
Water quality	Very polluted	Extremely polluted							Very polluted				

spread species in water are European bur-reed (*Sparganium emersum*), yellow water-lily (*Nuphar lutea*), arrowhead (*Sagittaria sagittifolia*), and small pondweed (*Potamogeton berchtoldii*). All plants in the river channel are resistant to the presence of organic matter in water. Reed canary-grass (*Phalaroides arundinacea*) and Scottish dock (*Rumex aquaticus*) are common among species growing along the river bank. Plants were absent in the channel part at stations 2–4 and 6. According to the WPI, these parts belong to the class of extremely polluted water, and the most unfavorable oxygen conditions were recorded, namely, in these sites: the concentration of dissolved oxygen in the surface water layer was ≤2 mg/dm^3. At the water edge, the plants were not found at stations 1, 4, and 5, the most polluted downstream section of the river. In addition to pollution, the development of plants in this section was limited by the presence of embankments on both banks at stations 1 and 4, and strong shading of the banks at station 4.

The species richness and diversity decreased downstream the river (Table 7); the plants were extremely inhibited beginning from station 6.

A similar tendency was observed in respect to the total projective cover at the stations (Table 7). Its highest values were recorded at stations 10 and 13, where vast and dense stands of *Nuphar lutea* developed. The channel area occupied by aquatic plants at stations 11 and 12 was smaller than in the neighboring stations, because it is one of the narrowest river sections and is almost completely shaded by trees along the bank. Because of the total absence of plants at the station or their presence only at the water edge, there are plots where the value of the projective cover equals to zero. They are stations located in the most polluted downstream reaches of the Okhta River, stations 2–4 and 6.

Table 4. Characteristic of macrozoobenthos at the surveyed stations in the Okhta River

Parameter	Stations				
	5	6	9	10	12
N, ind./m^2	173	1240	4120	1520	1147
B, g/m^2	1.7	2.8	213.3	20.2	6.4

N is the number of organisms and *B* is biomass; benthic organisms are absent in samples at stations 1–4, 7, 8, 11, and 13.

Water quality assessment in the surveyed sites based on the macrophyte data using *Sm* index has demonstrated that water quality deteriorates towards the mouth and is classified as very poor (Table 8).

A comparison of the classes of water quality obtained using the data on macrophytes with estimations based on hydrochemical characteristics demonstrates their close similarity. This is indicated by a high Spearman correlation coefficient for a series of data: WPI with *Sm* –0.76 at $p < 0.01$; i.e., characteristics of the vegetation cover are sensitive to the river pollution.

The following step was the determination of "the trophy level" and "the trophic status" of the parts in the Okhta River using aquatic macrophyte characteristics according to the methods presented in the works [23, 27, 30]. The terms are in quotes because they are traditionally applied for lakes, and watercourses differ essentially in the character of ecological processes [29]. However, some researchers use these terms in respect to rivers.

When determining the trophy level in the studied watercourses using *MTR*, *IBMR*, and *TIM* indexes, it has been found that their application under high anthropogenic load is not always possible. Macrophytes necessary for analysis were absent at stations 2–4 and 6. Only one indicator species was recorded at station 1 (a mouth part), so water quality was not assessed at these stations. Zoning of the studied section in the river channel according to the indexes is presented in Table 9. Waters at the stations where assessment was made have a rather high trophy level, which decreases downstream the river.

DISCUSSION

An analysis of hydrochemical parameters, the data on macrozoobenthos, and macrophyte characteristics was made at 13 stations in the Okhta River within the limits of St. Petersburg. Values of BOD_5, permanganate index, total iron, and concentrations of nitrites and phosphates are very high. The concentration of dissolved oxygen is lower than the norm at all stations. The river water is characterized by a high content of biogenic and organic matters and a rather unfavorable oxygen regime. Water pollution increases along the river length, though water in the near-mouth part of the river is less polluted than in the preceding parts, probably because of its dilution with waters of the Neva River. The calculation of the water pollution

Table 5. Saprobity at the surveyed stations in the Okhta River

Parameter	Stations				
	5	6	9	10	12
S	4.00	3.58	2.88	3.50	3.36
Zone of saprobity	P	P	A	A	A

S is the Pantle–Buck–Sládeček Saprobity Index; organisms are absent in the sample at stations 1–4, 7, 8, 11, and 13; P is polysaprobic and A is α-mesosaprobic.

index has demonstrated that the water quality in the Okhta River in regards to hydrochemical characteristics is very poor: it can be classified from very polluted to extremely polluted.

Our data agree well with the general tendency of the river pollution described by other researchers [10, 15, 20–22], and materials of the State Surface Water Monitoring Network [12]. It has been observed that concentrations of most matters increase towards the river mouth, and the concentration of dissolved oxygen decreases downstream the river. In addition, it was shown by E.S. Urusova [19] that from 1998 to 2013 there were some periods or years when concentrations of pollutants increased sharply.

The analysis of macrozoobenthos characteristics revealed considerable differences in the organism distribution among stations. Benthic organisms were absent in samples from some parts of the river, which may be explained by the heavy pollution of water and bottom sediments. It is also noted in work [2] that the water system of the Okhta River has a stable tendency to degradation according to zoobenthos characteristics.

According to the Pantle–Buck–Sládeček Saprobity Index, water in the studied sections of the river is characterized as polysaprobic or α-mesosaprobic, and saprobiological conditions deteriorate downstream the river. According to this index, waters in the Okhta River in 2002–2011 were mainly characterized as α-mesosaprobic and, in 2009–2011, oligochaetes were abundant in the surveyed parts, which indirectly indicates the increase in pollution with biogenic compounds [13]; i.e. all researchers, including the author of the paper, assess the water quality of the river according to the macrozoobenthos characteristics as poor.

Table 6. Abundance of macrophyte species at stations 1–13 in the Okhta River

Species	Ecogroup	Stations													
		1	2	3	4	5	6	7	8	9	10	11	12	13	occ.
In the channel:															
Nuphar lutea (L.) Smith	1	–	–	–	–	–	–	1	2	3	3	2	2	4	7
Ceratophyllum demersum L.	1	–	–	–	–	–	–	–	1	–	–	1	–	1	3
Callitriche palustris L.	1	–	–	–	–	–	–	–	–	1	1	2	2	3	5
Myriophyllum spicatum L.	1	–	–	–	–	–	–	–	–	–	2	–	–	–	1
Sparganium emersum Rehm.	2	–	–	–	–	1	–	2	2	3	3	3	2	3	8
Potamogeton alpinus Balb.	1	–	–	–	–	–	–	–	2	–	–	–	–	–	1
P. berchtoldii Fieb.	1	–	–	–	–	2	–	3	2	2	2	–	2	–	6
P. natans L.	1	2	–	–	–	–	–	1	2	–	1	–	–	–	4
P. perfoliatus L.	1	–	–	–	–	–	–	–	–	–	–	–	–	2	1
Sagittaria sagittifolia L.	2	–	–	–	–	–	–	1	1	3	3	3	3	2	7
At the water edge															
Rumex aquaticus L.	3	–	1	1	–	–	–	2	2	1	3	1	1	2	9
Persicaria amphibia (L.) S. F. Gray (terrestrial)	3	–	–	–	–	–	–	–	–	–	–	–	1	2	2
Ranunculus repens L.	4	–	–	1	–	–	–	–	–	1	–	–	1	1	4
Filipendula ulmaria (L.) Maxim.	5	–	–	–	–	–	–	–	–	–	–	2	–	–	1
Lysimachia vulgaris L.	4	–	–	1	–	–	–	–	1	–	–	–	–	1	3
Phalaroides arundinacea (L.) Rauschert	4	–	2	1	–	–	2	3	3	2	3	4	3	4	10
Carex acuta L.	3	–	–	1	–	–	–	–	2	–	–	3	4	4	5
Juncus effusus L.	4	–	–	–	–	–	1	–	–	–	–	–	–	–	1
Total number of species		1	2	5	–	2	2	7	11	8	9	9	10	12	18

Ecogroups: (1) hydrophytes, (2) helophytes, (3) hygrohelophytes, (4) hygrophytes, and (5) hygromeo- and mesophytes. Abundance: 1, <0.1%; 2, 0.1–2.5%; 3, 2.5–10%; and 4, 10–25%. Occ. is the occurrence at stations; "–" indicates that the species is absent.

Table 7. Macrophyte characteristics at the surveyed stations in the Okhta River

Parameter	Stations												
	1	2	3	4	5	6	7	8	9	10	11	12	13
S_{pc}, %	<5	0	0	0	<5	0	<5	<5	10	30	5	5	25
N_1	1	0	0	0	1	0	3	5	3	5	3	3	4
H_{1-5}, bit	0	0.9	2.3	0	0.9	0.9	2.7	3.2	2.9	3.1	3.1	3.2	3.4

S_{pc} is the total projective cover of macrophytes at the station, N_1 is the number of hydrophyte species (ecogroup 1), and H_{1-5} is the index of species diversity of all macrophytes (ecogroups 1–5).

In the year of studies, macrophytes in the Okhta River were represented by 18 species, 10 of which were developed in the channel part. The projective cover, species richness, and diversity decreased downstream right to the complete absence of true aquatic plants at some stations (2–4 and 6). These parameters are very low compared to watercourses in Leningrad oblast. For example, when comparing the floristic composition in the Okhta River and Oredezh and Chulkovka rivers, we may make a conclusion about the poorness of the flora in the studied river. Thus, the maximum number of species recorded at one station is 21 in the Oredezh River and 36 in the Chulkovka River [9], whereas the maximum number of species at one station in the Okhta River does not exceed 12 species.

Water-quality improvement found according to the hydrochemical parameters in the near-mouth part was confirmed by the data on the vegetative cover. Despite the complete absence of hydrophytes at stations 2–4, a community of broad-leaved pondweed (*Potamogeton natans*) developed at station 1. Values of the macrophyte index demonstrated rather poor water quality and the expecting tendency for its deterioration towards the river mouth. The assessment made using this index in 2004 yielded the same results: downstream the river the water quality varied from “polluted” to “very polluted” [8].

The trophy level at the surveyed stations was determined based on macrophyte characteristics. Values of *MTR*, *IBMR,* and *TIM* indexes indicate a high trophicity of the river parts. Attention should be paid to the fact that the stations in the Okhta River (9–13) with the highest trophic level were characterized as less polluted according to the WPI. On the whole, the trophic level decreases downstream of the river while the pollution increases. It is apparent that the use of indexes is difficult for such an anthropogenically transformed watercourse with a strong chemical pollution of water. Possibly, strong toxic pollution of some parts in the Okhta River probably has a hazardous effect on macrophytes and prevents the increase in the trophy level despite a high content of biogenic compounds in the river waters.

Table 8. Macrophyte index of water quality at the surveyed stations in the Okhta River

Parameter	Stations												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Sm, points	4	3	4	3	4	3	7	7	7	7	7	7	7
Water quality	Very polluted						Polluted						

The usefulness of the described indexes of trophy for an assessment of the watercourse in the northwestern region of Russia requires additional studies, because they have been developed for countries with different natural conditions such as France, Germany, and Great Britain. Nevertheless, there is a positive experience of the application of the indexes in the territory of Eastern Europe [18, 32], and the first attempt to determine the trophy level using *IBMR* was made in the Okhta River in 2004 and the trophy level was characterized as very high [8]. In the future we are planning to approve the methods of trophy assessment in watercourses of Northwest Russia with background values of hydrochemical characteristics.

The combined (integral) analysis of all materials shows that, on the whole, they are in agreement. A general tendency found as a result of the analysis of hydrochemical materials and the data on macrozoobenthos and macrophytes is the deterioration of water quality downstream of the river. Macrophyte characteristics reflect changes in hydrochemical parameters along the river length, and the macrophyte index of water quality is well correlated with WPI.

CONCLUSIONS

The results of all studies conducted have demonstrated that the Okhta River flowing through the city of St. Petersburg is a very polluted watercourse. According to the WPI it is characterized as a very polluted and extremely polluted watercourse. According to the Pantle–Buck–Sládeček Saprobity Index, parts of the river are classified as α-meso- and polysaprobic zones. The assessment according to the index based on macrophyte data has revealed categories of waters from polluted to very polluted ones. The *IBMR*, *MTR*, and *TIM* trophy indexes demonstrated high and very high trophy levels or mesoeutrophic and eutrophic status of different parts of the watercourse. The possi-

Table 9. Trophy indexes for the surveyed stations in the Okhta River

Parameter	Stations							
	5	7	8	9	10	11	12	13
TIM	2.44	2.52	2.39	2.97	2.95	2.96	2.94	3.02
Trophicity	Meso-/eutrophy	Meso-/eutrophy		Eutrophy				
IBMR	8.6	8.4	8.5	7.5	7.9	6.7	4.0	7.5
Trophy level	High	High		Very high				
MTR	37	36	37	32	32	30	32	31
Trophicity	Eutrophy/risk of eutrophy							

bility of applying macrophyte characteristics for water quality assessment is shown. For this purpose, the macrophyte index of river water quality may be used. All indexes calculated on the basis of macrophyte data present numerical formalized information. Thus, it may be convenient to use them in further multicriteria or an integral assessment of the ecological status of small watercourses.

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