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Structural Analysis of Water Quality Formation in an Urban Watercourse: Point, Non-Point, Transit, and Natural Components

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Abstract—The decomposition of water quality formation of city watercourse was carried out. The ratio of natural and anthropogenic (local and transit) components of the watercourse water quality were determined in the case of the Belaya River. The mass of pollutants entering the water body from Ufa City territory through sources of different categories, including point and non-point, was estimated. It was established that the ratio of pollutant masses from point and non-point sources varies in different phases of water regime, depending on the pollutant type. In the study, it is shown that the system of river water quality monitoring should be improved taking into account the features of its formation within urban territory.

Keywords: urban watercourse, water quality, point, non-point, transit, natural components

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INTRODUCTION

Cities and urbanized territories are among the main sources of the environmental pollution. They concentrate numerous economic facilities and activities that lead to deterioration of natural waters, imbalance and degradation of aquatic ecosystems; they reduce the recreational and aesthetic appeal of water bodies, and limit their use as the sources of household and drinking water supply. The most intensive is the load within large cities and historically developed industrial centers, often located on river bank in close proximity to each other and forming natural and technogenic complexes [10, 13, 15, 22].

Numerous point and non-point (diffuse) sources of pollutants entering water bodies are concentrated in cities. Such sources are wastewater discharges and emissions to the atmosphere of enterprises in various sectors of the economy, urban infrastructure, transport, landfills of underground sewage and industrial waste, landfills of solid domestic waste, accidents on sewage networks, fecal pollution resulting from the walking of pets and leaks from septic tanks, etc.

In the cities, various economic activities are carried out to transform water bodies and their catchments. The main negative factors of such activities that cause changes in the ways and rates of migration of chemicals include: an increase in the area of cover impervious for snowmelt and rain water (rooftops, asphalt and cobbled streets), soil compaction, changes in the structure of vegetation cover, construction and excavation work associated with the movement and storage of a large number of soil and building materials, the use of reagents to control ice-crusted ground, etc.

The water-protection and water-management policy in our country focuses on point sources, such as household and industrial wastewater releases. This is largely due to the fact that the damage to water bodies from this type of source is quite obvious and is well identified throughout the range of water quality indicators. The load onto a water body in this case can be estimated directly through the discharge of wastewater and the concentration of pollutants.

At the same time, non-point sources still remain in the shadow, despite the fact that domestic and foreign studies indicate their significant contribution to the deterioration of natural water quality. In particular, comparative examples in [17] clearly demonstrate that the water quality indicators such as BOD_5, suspended matter, and total coliform bacteria of urban storm water approximate to those of untreated domestic sewage.

Long-term studies of the diffuse pollution in the catchment area of the Ivankovo Reservoir, which lasted during 1980–2000, showed a high contamination of thawed and rainwater runoff from the territory of the Tver oblast cities. Thus, in the snowmelt runoff of the Tver City, the average concentrations of suspended solids at the beginning of snowmelt reached 1500 mg/L, and that of petroleum products was 18 mg/L. In Konakovo, the maximum values of COD and BOD_5 reached 1940 and 500 mg/L, respectively [14]. The calculations carried out in [3] show that in the late 1990s, surface runoff from the territory of Moscow to water bodies had oil products 1.8 times and suspended substances almost 24 times higher than the wastewaters of all enterprises operating in the city.

The most common types of pollutants entering water bodies from urban areas with surface runoff are heavy metals, petroleum products, nutrients, various types of persistent organic pollutants, and other types of xenobiotics, including drug residues. Each of these types of substances has its own specific sources of formation and has an individual mechanism and duration of action in aquatic ecosystems [20].

Typical examples of the urbanization impact on the ecological state of urban water bodies were obtained in special studies conducted at 125 river sites in Connecticut (USA) in 2005–2006 [4]. In particular, it was shown that in none of such areas with more than 11–12% of catchment area covered by impervious pavement, water quality did not meet the state-accepted criteria for a healthy aquatic ecosystem.

The quantifying of the load onwater bodies from non-point sources is difficult, for the following reasons:

—there is a wide variety of sources, and pollution from them occurs spontaneously and is characterized by considerable spatio-temporal variability;

—pollution is formed indirectly as a result of surface washout from impervious territories, removal of erosion products, seepage through contaminated soil, dry and wet deposition of substances from the atmosphere, etc.;

—there is no system for monitoring diffuse pollution, and the control of pollutants in their places of origin faces technical, organizational, and financial problems [2, 16, 19].

At the same time, the separate evaluation of the contribution of diffuse and point sources of pollution is extremely important for managerial decision-making in the field of protection and rational use of water resources. The complexity of this evaluation is due to the relative uncertainty of reported data on water quality accepted in the existing practices of water use, as well as insufficient for these purposes amount of laboratory control points and the sampling frequency within the system of State Hydrochemical Monitoring of water bodies.

Even assuming that the researcher has data on the contamination of a river section from point sources (for example, information provided by enterprises in the form of 2TP (vodkhoz)), laboratory control data, measured water discharges and other hydrometeorological information, data on the structure of land use, the estimation of the diffuse component will not be easy and can only be performed in a general form, reflecting the integral contribution of all non-point sources. An attempt of such an assessment for urbanized area was carried out in this study.

NATURAL AND ANTHROPOGENIC FACTORS FORMING THE WATER QUALITY OF URBAN WATERCOURSE. CHARACTERISTICS OF THE STUDY OBJECT

An example of a water body that is affected by point and non-point sources of pollution is the Belaya River—the largest tributary of the Kama [24]. In its middle course, cities—industrial centers with enterprises of predominantly oil refining, chemical and petrochemical industries are located along on the banks of the river, forming a large natural and anthropogenic complex. One of such centers is Ufa with a population more than 1 million.

The city is located within the Pribelsk-Ufa watershed plain mainly in the interfluve of the Belaya and Ufa rivers (Fig. 1). The plain is dissected by a gully network of erosion-karst origin, as well as valleys of rivers and streams. In the formation of urban area relief, in addition to the natural (erosion, karst, etc.), technogenic processes (filling ravines, karst funnels, and lakes; reclaiming sites; erecting dams; digging ditches, etc.) are actively developing [1].

The main underlying rocks in this area are sandstones, limestones, dolomites, and gypsums, which are highly leachable. The most widespread are gray forest soils and chernozems, which provide a greater return of salts than other soils do. The increased erosion of soils contributes to pollutants entry into the water.

The climate of the territory is continental with a warm summer and a long, moderately cold winter. The average annual air temperature is +3.4°C. The annual precipitation is 557 mm, the average annual relative humidity is 75%.

The alimentation of the Belaya River is mostly snow. The spring flood (April–May) accounts for more than 60% of its annual runoff. The share of summer–autumn runoff (June–November) does not exceed 25–30% per annum. Winter low-water period is set at the end of November, minimum water discharge is observed in February–March. Water availability of the river is also subject to significant interannual fluctuations: the annual runoff of the river of the high-water year is ~6 times higher than the runoff of the low-water year.

The heterogeneity of the chemical composition of soils and rocks, together with the periodic predominance of the waters of various types (surface and subsurface water or groundwater) in the river alimentation lead to natural intra-annual changes in the chemical composition of river water. The anthropogenic factors also have a significant impact on the hydrochemical regime of the river.

Within the Ufa territory with an area of 765 km^2, there are both unchanged sites occupied by natural forms of relief, water objects and vegetation, and sub-

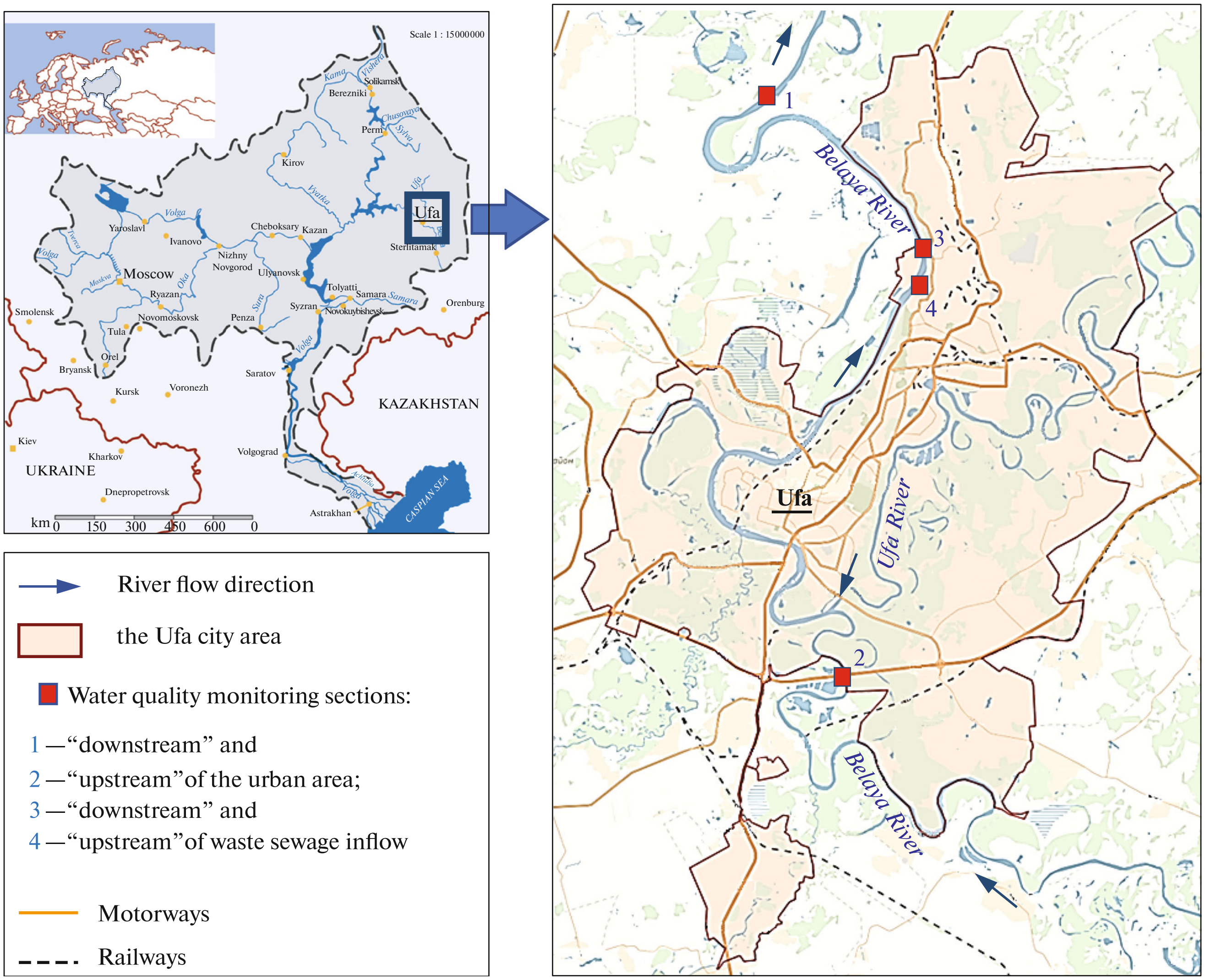

Fig. 1. Map of Ufa City and water quality monitoring sites on the Belaya River.

stantially transformed—the territory of industrial enterprises, urban development, etc. [18].

Industrial enterprises occupy over 7% of the city’s territory. Within its boundaries, there are about 200 large and medium-size production facilities, including three oil refineries, a synthetic alcohol plant, a chemical plant, a motor-building plant, oil-producing equipment, a cable, electrical, woodworking, and construction industries, etc. The centralized water supply and sanitation for the population, city enterprises and organizations is carried out by MUE (Municipal Unitary Enterprise) “Ufavodokanal.” The largest industrial enterprises have their own treatment plants and organized sewage water discharges into the Belaya River.

Ufa has no joint storm sewage system. Rain and melt water from the city’s territory is drained into the nearest water bodies, ravines or relief depressions that have a slope toward the rivers. The surface runoff from the sites of several of the largest industrial enterprises is disposed of together with industrial wastewater. The majority of industrial enterprises either do not have storm water drainage at all, or are only partially equipped with it.

Built-up areas (buildings, roads, engineering structures) occupy over 12% of the urban area. The automobile, railway, air, pipeline, river transport, and also the corresponding transport infrastructure are developed. The proportion of asphalt pavement from the total area of roads and embankments is 86%.

About 30% of the city’s area is occupied by green plantations, which are distributed extremely unevenly over it [23].

Table 1. Information about the analyzed characteristics of the Belaya River, Ufa City, and study periods

The study period	1938–1950	1986–2002
Analyzed water quality characteristics	Total mineralization, chlorides, sulfates, nitrate nitrogen, nitrite nitrogen, total iron	Total mineralization (dry residue), chlorides, sulfates, suspended substances, petroleum products, phenols, surfactants, BOD_5, COD, ammonium nitrogen, nitrogen nitrate, nitrogen nitrite, phosphates (total phosphorus), iron, copper, zinc
Average multiyear flow rate, m^3/s	788	796

INITIAL DATA

The data used to obtain quantitative estimates of the various components of Belaya River water quality within the city of Ufa are:

—data on observations of the water chemistry and discharge rates of the Bashkir Hydrometeorology and Environmental Monitoring Department (Bashkirskoe UGMS) in two sections on the Belaya River, located downstream and upstream of the city area (sections 1 and 2 in Fig. 1);

—data on monitoring the river water quality by the Ufavodokanal enterprise in the zone of influence of sewage discharges through the outlet from urban sewerage treatment plants in two control sections: 500 m downstream and 500 m upstream from the sewage discharge (sections 3 and 4 in Fig. 1);

—data of statistical reporting forms 2TP (vodkhoz)—information on the content of pollutants in the sewage discharged into the river by the enterprises of Ufa.

Belaya River water quality components were evaluated by 16 indicators (Table 1). Most of the indicators showed that the quality of river water does not meet the standards established for various types of water use [11, 12].

There are different numbers of water samples collected by Bashkirskoe UGMS in the study periods (Table 1). The best studied is the period of 1986–2002, when the annual number of water samples in one section varied from 12 to 40, and covered the whole annual cycle of the river's water regime. In the period 1938–1950 the number of collected samples was less and ranged from 2 to 21 per year. In both time periods, the greatest number of hydrochemical observations referred to the summer–autumn low runoff.

MUE Ufavodokanal once a month determines the concentrations of pollutants in the river water in each of the control areas. The annual statistical reporting forms 2TP (vodkhoz) contain information on the amount of maximum permissible discharges established for each enterprise in Ufa and the amount of pollutants actually discharged in the sewage water over the year.

THE METHOD FOR CALCULATION OF RIVER WATER QUALITY CHARACTERISTICS

The decomposition of factors forming urban watercourse water quality is carried out and its main genetic components are identified (Fig. 2):

—a natural background components, caused by natural factors not related to human activity;

—local pollution from urban areas through point and non-point sources (additionally with tributaries in case of their inflow into the watercourse within the city);

—transit of pollutants from upstream urban areas or other sources.

The method for evaluating the characteristics of natural and anthropogenic factors forming water quality in watercourses within urban areas is shown in Fig. 3. The figure shows that the determination of quantitative characteristics is based on a consistent calculation of the mass of chemicals dissolved or suspended in the flow (hydrochemical runoff). The content of these chemicals is due to the genetic components mentioned above. The determination of chemical amounts contained in a water body, rather than in discharged wastewater, allows indirectly taking into account the transforming and self-cleaning ability of a particular water body.

To account for the interannual and seasonal river flow variability and the chemical substance concentrations in river waters, calculation of hydrochemical runoff was carried out in different phases of the water regime and over a multiyear period.

THE DETERMINATION OF BACKGROUND CHEMICAL CONCENTRATIONS IN RIVER WATER

At present, information about the chemical composition of river water in the Belaya River basin under natural conditions is not available. The beginning of systematic observations of the river water chemical composition (1938) coincided with the period when economic activity was already being conducted on the catchment area. In [15] it was established that its intensity and, accordingly, the anthropogenic load on the Belaya river is characterized by a large time irregularity. The period from 1938 to 1950, before the start of the operation of large industrial facilities, which sig-

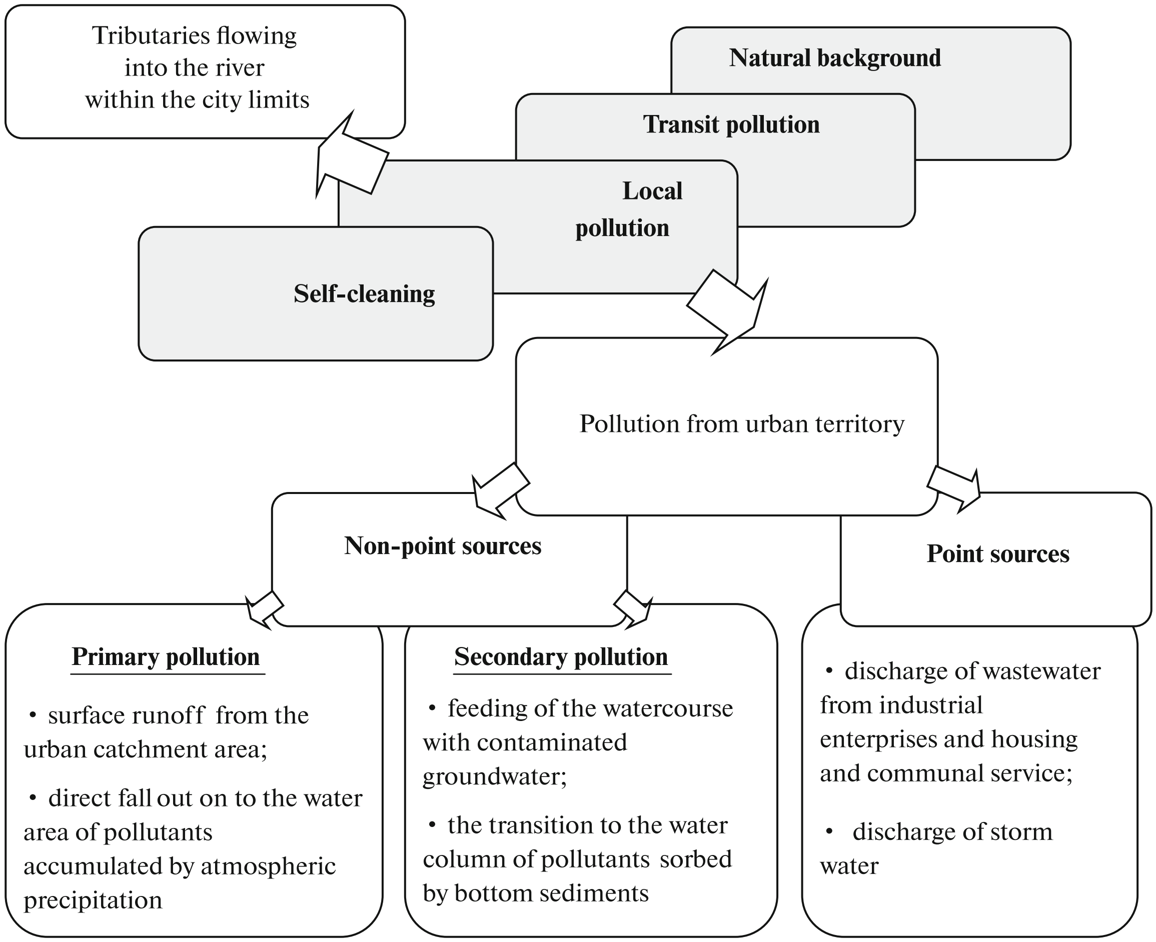

Fig. 2. Decomposition of urban watercourse water quality formation.

nificantly affected river water quality, is characterized by the lowest chemicals content in it (Table 2). This period is conditionally called the period of low anthropogenic impact.

In the 1950s and 1960s, large industrial facilities were put into operation, located on the Belaya River banks. This period is transient with an unsteady nature of anthropogenic impact. By 1969, most of the existing and currently operational facilities have already been commissioned, their effect considerably exceeding the anthropogenic impact on the Belaya River for many previous years. Therefore, the period from 1969 to 2002 is conditionally called the period of intensive anthropogenic impact. At this time, there is a significant change in the chemical composition of river water in comparison with the first period (Table 2). For example, the average annual chloride content increased fivefold; nitrate nitrogen, nitrite nitrogen, and total iron increased 2–4 times; and sulfates, 1.5 times.

The study of the annual changes in the chemical composition of river water during the *low* anthropogenic impact shows that they correspond to the natural processes taking place on the catchment area and in the river itself. The change in the content of the main ions is due to a change in the water supplying the river. Changes in the content of nitrogen compounds actively involved in the life of aquatic organisms are associated with the consumption of biogenic phytoplankton and denitrifying bacteria. The iron content of river waters is associated with its leaching and wash off from the surface of catchment area [5, 6, 8].

As shown in [6], the close correlation between the water discharge and its content of main ions, which is specific of water courses under natural conditions, was observed in the Belaya River only in period 1938–1950 ($0.68 < R < 0.94$). During the period of intensive anthropogenic impact, the closeness of the correlation decreased significantly ($0.03 < R < 0.64$).

These features of the Belaya River hydrochemical state in the period of low anthropogenic impact indicates its proximity to the natural conditions. Therefore, the values of hydrochemical indicators monitored during this period are used in calculations of N (Fig. 3) as "background."

1. Natural background (physical and geographical conditions for the formation of water chemical composition), N, tons	$N = C_N Q_N T$
2. Local watercourse pollution from urban area, V, tons	$V = \Delta C_{1,2} Q_V T$
3. Total amount of pollutants entering the watercourse from the catchment area, D, tons	$D = C_1 Q_1 T$
4. Transit pollution of the watercourse coming from upstream sources, A, tons	$A = D - V - N$
5. The share of natural (N'), local (V') and transit (A') factors in the watercourse pollution	$N' = N/D;\ V' = V/D;\ A' = A/D$
6. The amount of pollutants that enter the watercourse from urban point sources, V_P, tons	$V_P = \sum_{i=1}^{n} \Delta C_{3,4i} Q_V T$
7. The amount of pollutants that enter the watercourse from urban non-point sources, V_{NP}, tons	$V_{NP} = V - V_P$
8. The share of point (V'_P) and non-point (V'_{NP}) sources in local watercourse pollution	$V'_P = V_P/V;\ V'_{NP} = V_{NP}/V$

Note:
C_1 and C_2 are the averages for the calculation period, the concentration of pollutant in the sections downstream and upstream of the city, respectively, mg/L;
$\Delta C_{1,2}$ are the averages for the calculation period, the difference in pollutant concentrations in the sections downstream and upstream of the city, mg/L;
C_N is the average for the calculation period background concentration of a chemical component, mg/L;
C_3 and C_4 are the average for the calculation period of the concentration of pollutant in the sections downstream and upstream of each i-point wastewater discharge, respectively, mg/L;
$\Delta C_{3,4}$ is the average for the calculation period of the difference in pollutant concentrations in the sections downstream and upstream of the i-point wastewater discharge, respectively, mg/L;
n is the number of point wastewater discharges within the urban area;
Q_N is the average water discharge in the river in the background period , m^3/s;
Q_V is the average water discharge in the river in the city over the estimated period, m^3/s: $Q_V = (Q_1 + Q_2)/2$;
Q_1 is the average water discharge in the river downstream of the city over the estimated period, m^3/s;
Q_2 is the average water discharge in the river upstream of the city over the estimated period, m^3/s;
T is a conversion factor that takes into account the different dimensions of the volume and mass values included in the formula, and also the duration of the calculation period in seconds: for the year the coefficient T is 31.53; for spring flood period, 5.27; for the summer–autumn period, 15.81; and for the winter low-water period, 10.45.

Fig. 3. The calculation method for quantitative characteristics of urban watercourse water quality formation.

Table 2. The concentrations of chemicals in the Belaya River in Ufa City in periods with different level of anthropogenic impact [5, 8, 15]

Hydrochemical index	Average annual, mg/L	Measured value range, mg/L	In different phases of the water regime, mg/L		
			spring flood period	summer–autumn period	winter low-water period
The period of low anthropogenic impact					
Total mineralization	340	103–693	216	391	506
Sulfates	73.4	11.5–200	42.1	91.1	126
Chlorides	11.6	0.1–43.0	5.90	12.4	18.3
Nitrate nitrogen	0.79	0.05–1.50	0.76	0.70	0.94
Nitrite nitrogen	0.016	0.001–0.060	0.018	0.015	0.012
Total iron	0.11	0.01–1.58	0.18	0.18	0.09
The period of intensive anthropogenic impact					
Total mineralization	516	176–1062	415	539	642
Sulphates	111	27.7–220	79.0	128	139
Chlorides	54.8	22.9–386	45.0	58.9	91.6
Nitrate nitrogen	1.81	0.02–4.47	1.57	1.46	2.28
Nitrite nitrogen	0.047	0.003–0.839	0.055	0.045	0.062
Total iron	0.45	0.02–2.16	0.69	0.34	0.16

DETERMINATION OF LOCAL POLLUTION FROM THE URBAN TERRITORY

The Belaya River local pollution (V) from the Ufa City territory occurs through point and non-point sources, and also comes with tributaries flowing into the river within the city boundaries. The calculation was carried out for the urbanized river section 35 km long between two hydrochemical stations located upstream and downstream of the Ufa City (Fig. 1) for the period 1986–2002.

The results of calculation show that the range of annual runoff values of the studied pollutants varies considerably from ~200 tons/year (the runoff of phenols and copper runoff) to ~2.1 million tons/year (the runoff of suspended matter and mineral substances).

The greatest amount (about 50% of the total annual runoff) of pollutants from the Ufa territory comes to the Belaya River during the spring high water; and the smallest (about 7%), during the winter low-water season. The maximum excess of hydrochemical runoff in the high-water compared with the winter low-water period is observed for iron and petroleum products (~15 times); and the lowest, for phenols and nitrogen nitrite (~1.5 times).

The results of local pollution calculations from the urban area coincide with the state control data. According to the Ministry of Nature Management and Ecology of the Republic of Bashkortostan [11, 12], more than 60% of cases of high and extremely high pollution of the Belaya Riverare annually recorded during the spring flood.

In two spring months, the river receives from the city through sources of both categories the bulk of iron (67% of the annual runoff), mineral substances (63%), petroleum products and phenols (59% each), nitrates, phosphates, copper, as well as organic substances estimated by BOD_5 (51% each).

In the summer–autumn period, the largest amount of suspended solids (60% of annual runoff), zinc, and organic substances, estimated by the COD index (46% each), comes from the city territory.

Apparently, a significant flow of pollutants from urban area during the period of intensive anthropogenic impact led to changes in the river hydrochemical regime compared to the period of low anthropogenic impact (Table 2):

—a decrease the multiplicity of excess of sulfates and chlorides in the winter low-water period relative to the spring high water;

—an increase in the multiplicity of excess of iron content in high water relative to other phases of water regime.

DETERMINATION OF THE RELATION OF NATURAL, LOCAL AND TRANSIT POLLUTION

For the period of 1986–2002, pollutant characteristics were calculated, including the pollutant mass entering the Belaya River from the whole catchment area (D) and the transit pollution (A), caused by the pollutants from upstream sources (Fig. 3).

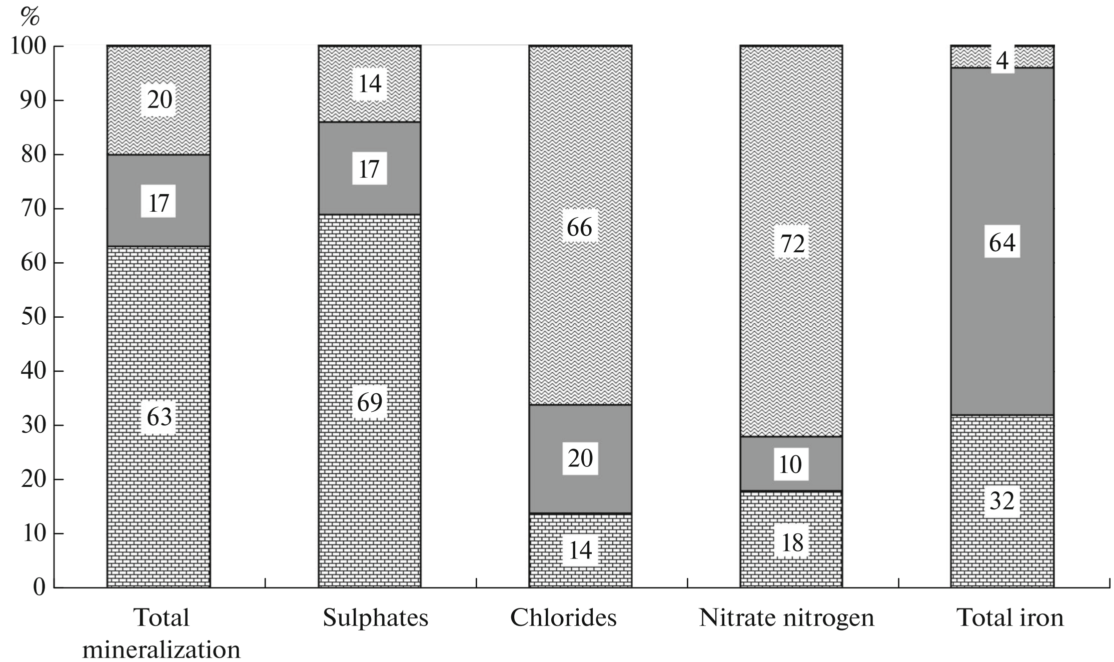

Fig. 4. The ratio of natural and anthropogenic factors forming Belaya River water quality within the Ufa City: natural background, transit pollution, local pollution.

A comparison of the calculation results shows the following. The content of suspended solids, petroleum products, phenols, surfactants, ammonium nitrogen, iron, copper, zinc, and organic substances estimated by BOD_5 in river water is mainly due to local anthropogenic sources. The share of the city (V') in the annual runoff of these pollutants varies in the range of 64–100%.

Chlorides, nitrate nitrogen, as well as organic pollutants estimated by the COD indicator, come mainly from upstream sources. This can be seen from the insignificant share of local urban sources (V') in river water pollution (10–35%) by these substances.

The comparison of the values of natural (N), local (V), and total (D) hydrochemical runoff of the Belaya River shows (Fig. 4), that the share of transit pollution (A) can reach significant values. For example, the transit component is the source of 66% of chlorides and 72% of the nitrogen nitrate content in river water in the section of Ufa City.

Physical and geographical conditions (a natural factor) have the greatest impact on the content of sulfates and minerals in water (63–69%). The concentration of iron in river water is 64% due to the influence of urban areas.

The established ratio of local and transit Belaya River pollution testify to the impossibility of solving water protection problems in a particular section of the river.

CALCULATION OF POLLUTION FROM POINT SOURCES

The main point source of pollution from Ufa City territory is the discharges of treated sewage from MUE Ufavodokanal. According to state records, the enterprise is the source of about 35% of the wastewater discharge in the region [11, 12]. The system of urban sewage treatment facilities receives not only domestic and industrial wastewater from the population and enterprises of the social sphere, but also the effluent of the majority (over 180) of city's enterprises that have undergone local treatment at the production site [9].

The Administration of Ufa City approves the values of permissible pollutant concentrations in the sewage discharged by enterprises and organizations into the urban sewage system. The analysis of compliance with the approved standards by Ufavodokanal shows that often the actual pollutant concentrations in the effluent taken from the individual enterprises exceed the allowable levels.

About 85–90% of the wastewater entering the treatment facilities is sent to the stations for complete biological treatment. The removal of biogenic elements and organic and inorganic substances of industrial origin is not provided by treatment facilities. Due to the insufficient performance of treatment plants, the remaining 10–15% of effluents is discharged into the watercourse without treatment as part of the mixture with the wastewater that has been treated. In general, according to the Ufavodokanal data, due to the existing treatment system, the standards of maximum

Table 3. Discharge of pollutants with sewage from the Ufavodokanal enterprise in the Belaya River (based on statistical reports 2TP (vodkhoz))

Year	Discharge type	Discharge mass, *t*/year						
		petroleum products	surfactants	sulfates	chlorides	copper	phosphates	nitrates
1995	Actual	113	17.6	28396	8972	10.9	1308	9074
	Maximum permissible	8.48	84.5	21420	50699	0.166	33.8	2406
1996	Actual	109	25.9	27845	9085	3.58	1235	8948
	Maximum permissible	8.48	84.7	16946	50838	0.166	33.9	3677
1997	Actual	80.0	26.3	25736	8238	2.18	321	7557
	Maximum permissible	8.45	84.5	16900	50699	0.169	33.8	6760
1998	Actual	78.5	16.3	27796	8316	1.747	364	7460
	Maximum permissible	8.45	84.5	16900	50699	0.169	33.8	6760
1999	Actual	58.8	17.8	25126	8142	3.01	361.1	8799
	Maximum permissible	8.45	84.5	16900	50699	0.169	33.8	6760
2000	Actual	233	49.2	28039	7932	2.22	271	5889
	Maximum permissible	6.80	68.0	13596	40789	0.136	27.2	5439

permissible discharges in the Belaya River are exceeded by many water quality indicators (Table 3).

The calculation of Belaya River pollution by point sources in the Ufa City (V_P) for period 1986–2002 was carried out in several stages. At the first stage, in accordance with the methodology (Fig. 3), the amounts of pollutants contained in the river as a result of the Ufavodokanal enterprise discharges was determined. At the second stage, according to the report forms 2TP (vodkhoz) of city enterprises, the shares of the water supply and sewage service in the total Belaya River pollution from all city point sources, with independent releases of sewage, was calculated. The total river pollution by point sources is calculated in accordance with the contributions of MUE Ufavodokanal to it.

The comparison of the estimates of the effect of Ufavodokanal on the Belaya River and information about the pollutant contents in the discharged wastewater (forms 2TP (vodkhoz)) for the same period showed that there is a significant difference between them [7]. For example, the excess of the calculated values over the statistics is 98% for heavy metals and phenols; 97% for iron, 94% for suspended substances, etc. According to the reported enterprise data, the discharge of surfactants is 25 t/year, but the results of calculations show 911 t/year, i.e., 36 times more. According to the enterprise data, the chlorides discharge is 7241 t/year, while, according to calculations, these are 213131 t/year, i.e., more than 29 times greater, etc. The results of calculations for nitrate and nitrite nitrogen were in best agreement with the report data – the difference is 1.7 and 2.6 times, respectively.

These differences can be explained by the existing system of sampling sewage water at enterprises. The main feature of industrial wastewater is the varying pollutant concentrations in them during the day: at the beginning of the working day the concentrations are low, then it can rise sharply, and then again decrease to the initial level. The pollutant concentrations can be vary within three orders of magnitude. If there is no automatic means at the enterprises to continuously monitor the pollutant concentrations in wastewater, the control is based on one-time water samples, and the result is presented as a daily average. The subjectivity of this approach can introduce significant errors in determining the actual pollutants discharge [21].

According to the forms 2TP (vodkhoz), the shares of the enterprise "Ufavodokanal" in the Belaya River pollution from point sources are 73–81 for suspended matter, 87–93 for oil products, 88–93 for copper, 99 for phosphates, 90–93 for COD, 92–95 for phenols, 60–70 for iron, 50 for sulfates, 25% for chlorides, etc.

The calculation results show that 94% of the annual pollutant mass from urban point sources are estimated by the total mineralization index. The bulk of pollutants comes in the spring and exceeds the flow to other phases of the water regime from 2.2 times (for phenols) to 49 times (for suspended solids). This may be due to the fact that, in addition to domestic and industrial wastewater, storm water is partly involved in the formation of urban wastewater in the urban sewage system because of its poor performance or the lack of storm sewage [9]. It is also possible that unauthorized and/or accidental wastewater discharge from individual enterprises during periods of higher water can have their effect.

Table 4. The mass ratio of pollutants received in the Belaya River from the Ufa City territory from different sources in the period 1986–2002, %

Pollution sources	Water regime phase			For one year
	spring flood period	summer–autumn period	winter low-water period	
Sulphates				
Point	58	30	12	100
Nonpoint	–	–	–	–
Chlorides				
Point	61	18	15	94
Nonpoint	–	6	–	6
COD				
Point	36	21	8	65
Nonpoint	5	23	7	35
Petroleum products				
Point	30	9	6	45
Nonpoint	28	27	0	55
Nitrate nitrogen				
Point	65	24	11	100
Nonpoint	–	–	–	–
Ammonia nitrogen				
Point	36	13	6	55
Nonpoint	11	24	10	45
Iron				
Point	50	17	4	71
Nonpoint	17	11	1	29
Surfactants				
Point	44	33	15	92
Nonpoint	0.5	7.5	–	8
Phenols				
Point	9	5	4	18
Nonpoint	35	25	22	82
Copper				
Point	46	43	11	100
Nonpoint	–	–	–	–

DETERMINATION OF THE POLLUTION FROM POINT AND NON-POINT SOURCES

The estimates of the Belaya River pollution from non-point sources in the Ufa City (V_{NP}) show that the greatest amount of pollutants (64%) enters the river in summer and autumn, and the smallest amount (about 5%), in winter. The maximum excess of hydrochemical runoff from non-point sources in summer and autumn in comparison with winter was recorded for the total iron and oil products (~200 times). The major annual pollutant mass from non-point urban-sources are suspended solids (92%), and 4% are organic substances estimated by COD.

The comparison of Belaya River pollution from the Ufa City territory, coming from point (V_P) and non-point (V_{NP}) sources, shows that the ratio of point to non-point pollution varies in different phases of water regime and depending on the pollutant type (Table 4; Fig. 5).

The results of the calculations indicate that the main cause of the high pollution in the Belaya River within the Ufa City in the flood period is the inflow of pollutants from point sources. The annual inflow from point sources accounts for 100% of sulfates, nitrates, phosphates, and copper; about 80–90% of chlorides, surfactants, and zinc; more than 50% of organic substances, evaluated by COD, nitrogen ammonium, and

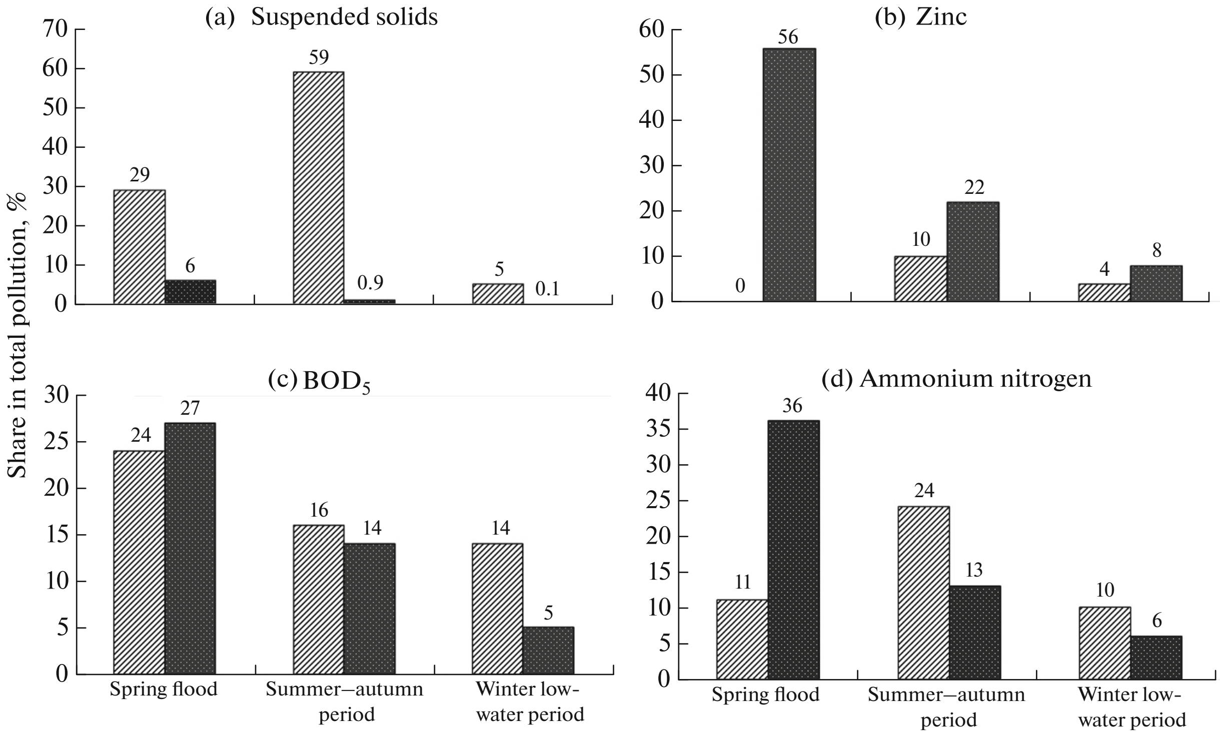

Fig. 5. The ratio of point and non-point Belaya River pollution from the Ufa City territory in various phases of the water regime: ▨ non-point sources, ■ point sources.

iron. Mineral substances are the main (by mass) pollutants of point origin.

At the same time, non-point sources account for 93% of suspended solids, 82% of phenols, 76% of nitrates, and 54% of readily oxidizable organic substances, estimated by BOD_5. The major pollutant (by mass) from such sources is suspended matter.

CONCLUSION

The main genetic components of urban watercourse water quality are natural background, local pollution, and transit pollution. An approach is proposed to determine the natural background concentrations of pollutants in a water body based on a joint analysis of the dynamics of long-term anthropogenic load on the river catchment and the pollutant concentrations in its water. The comparison of the calculated values of the genetic components of water quality indicates the need for a basin-scale approach in the management of Belaya River water quality in the Ufa City.

The amounts of pollutants entering the water body from the Ufa City territory from point and non-point sources, averaged over a period of many years, were evaluated for a year and in different phases of the water regime. The contribution of non-point sources to river pollution was found to be considerable, and, for some pollutants, to exceed the point-source contribution. The mass ratio of point to non-point pollution varies in different phases of water regime, depending on the pollutant type.

The expediency of improving the system for water quality monitoring in the Belaya River, taking into account the peculiarities of its formation within urban territory, was shown. The uncertainty in the reported data of the point pollution impact on the river water quality, adopted in existing water use practices, makes it difficult to reliably estimate the impact of non-point pollution sources.In the absence of monitoring system for non-point sources, only an integral assessment of their contribution to the river water pollution is possible.

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