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WATER QUALITY AND PROTECTION: ENVIRONMENTAL ASPECTS

Anthropogenic Transformation of Aquatic Environment Composition in the Lena River Mouth Area

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Abstract—Variations in the hydrological–hydrochemical state of the aqueous medium in Lena mouth area. The hydrological regime of the river and variations in qualitative water composition in the mouth area are described in detail. Anthropogenic load is estimated in terms of the inflow and the modulus of inflow of pollutants.

Keywords: Lena mouth area, variations in hydrological regime, anthropogenic load, biogenic elements, pollutants.

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THE LEVA RIVER MOUTH AREA AS A GEOGRAPHIC OBJECT

The Lena River mouth area is a "specific physiographic object covering the area of river outflow into a receiving water body" [19]. The mouth area usually consists of the "part of the lower river reach (mouth reach of the river), including the delta ... and the part of the nearshore zone of the receiving water body (nearshore zone of the river mouth)" [20]. The river mouth area refers to the deltaic type. The Lena delta area covers from 28000 to 32000 km^2.

As in the case of many other mouths, this is an area characterized by the "specific, often azonal landscape, transitional hydrological regime, radical changes in the physical, chemical, and biological features of water masses, increased biological productivity; this area represents a sedimentological, morphological, geochemical, and biological barrier between a river and a receiving water body" [20].

The boundaries of the river mouth area are outlined by the intense manifestation of mouth processes [13]. The scheme of the Lena River mouth area is shown in the figure, its structure and boundaries are given in Table 1.

The river (upper) boundary of the mouth area begins from the site of the river channel branching to form delta branches with reference to the island of Tit-Ary. This island and the source of the first left branch Bulkury are considered to be the Lena delta head. It is located in the zone of conjugation of the narrowed (9 km) lower reach of the Lena River (the so-called Lena tube) and the funnel-shaped widening of the valley at the island of Tit-Ary (175 km from the mouth cross section of the navigable Bykov branch) [12, 19]. Tidal water level fluctuations are not observed upstream of the delta head; therefore, the deltaic and mouth reaches of the Lena River are in agreement.

The sea (lower) boundary of the river mouth area (the outer boundary of the nearshore zone of the river mouth) is usually in line with the ultimate distance of seaward propagation of the outer part of the zone of mixing of river and sea water [13, 19].

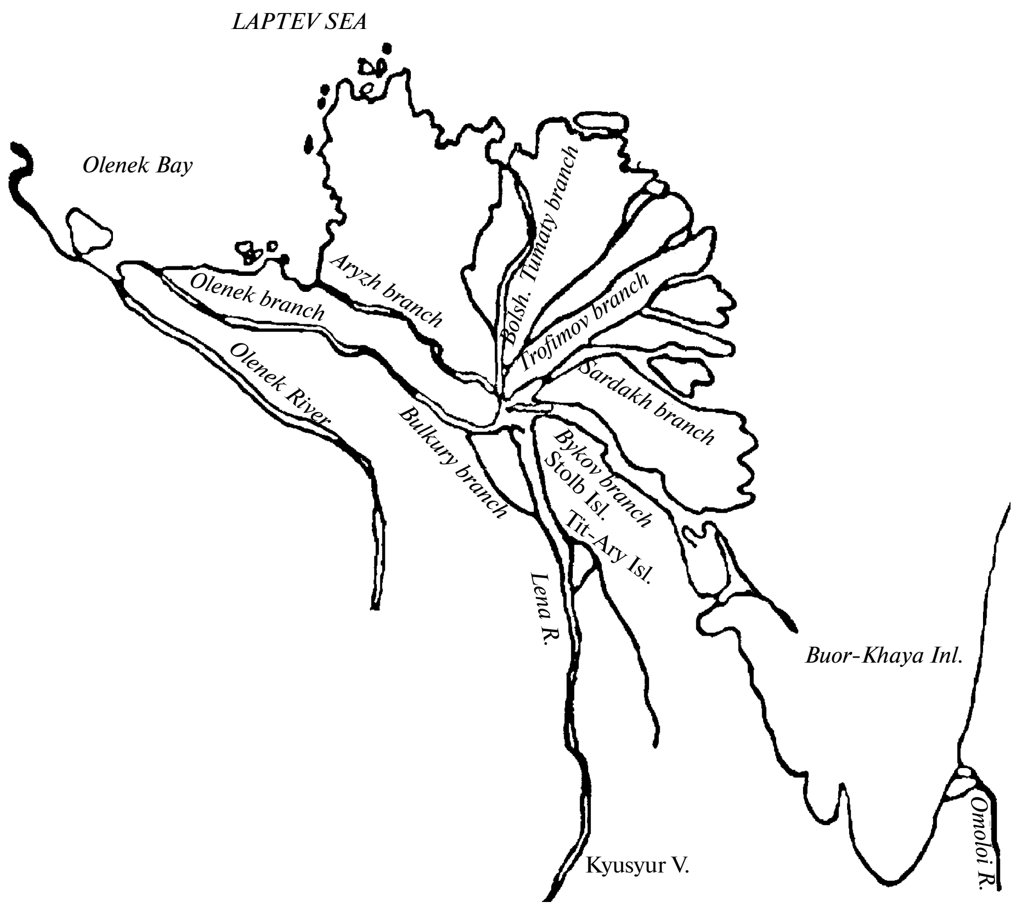
The main fork of the Lena River branching is located in the area of the rocky island of Stolb; among the large deltaic branches are the branches of Olenek, Tumaty, Trofimov, and Bykov. The Trofimov branch is actually the continuation of the main river channel (figure).

The Lena delta area with the head at the place of branching of the left Bulkury branch (near the island of Tit-Ary) is 32000 km^2 and its area with the head near the island of Stolb is 28000 km^2. The delta length in different directions averages 150 km [19, 26].

The drainage system of the Lena delta is very complicated; it has numerous branches and lakes. It includes 6089 watercourses, the length of which totals 14626 km, and 58728 lakes 3196 km^2 in total area. There are more than 1600 islands in the delta, the density of the channel network is 0.34 km/km^2 in the eastern part of the delta and 0.13 km/km^2 in the western part [19].

The Lena River runs in the single-branch channel 2 km wide from the outlet at the village of Kyusyur to the island of Tit-Ary.

The large area of the delta, its meridional elongation (owing to this, it forms a deep outlet in the Laptev Sea), and uneven distribution of the Lena River thermal flow over the delta area are responsible for macroclimatic differences in the delta parts [8]. The Lena



Schematic map of Lena River Mouth Area [1].

River mouth area may by considered as a peculiar geographic object, which involves the area of the river outflow into the Laptev Sea, has definite boundaries, and is under the impact of specific mouth processes based on the "dynamic interaction, mixing and transformation of water mass of a river and a receiving water body, deposition and redeposition of river and partially sea sediments" [20].

The river hydrological regime prevails in the mouth reach of the river but it is under the impact of the receiving water body (sea). On the contrary, the hydrological regime inherent in the receiving water body (sea) prevails in the nearshore zone of river mouth but it is under the strong impact of the river. The intensity of impact of the receiving water body on the river regime and the river flow on the sea regime decreases in the direction upstream the river and in the seaward direction from the mouth cross section, respectively. Like all mouth areas, the river reach under study is subject to a strong impact of continental factors, such as the flow of polluted river water and economic human activities.

TYPICAL FEATURES OF VARIABILITY OF HYDROLOGICAL REGIME OF THE LENA RIVER MOUTH AREA

The hydrological regime of the Lena River mouth area greatly depends on the specific features of the river water regime, which is typical of the rivers of Eastern Siberian type and has a prolonged period of snowmelt floods and rainfall floods. The alimentation of the river in its lower reaches is mixed, snowmelt feeding prevails.

The water level in the mouth area varies significantly from 23.2 m at the village of Kyusyur to 9.0 m at the source of the Bykov branch (the island of Stolb) and 2.9 m in the Neelov Bay [10, 19].

The mean long-term water runoff at the river outlet near the village of Kyusyur (the watershed area is 2430000 km^2) amounts to 536 km^3. From 1980 to 2005, the maximum volume of inflow was 728 km^3 (1989) and the minimum volume of inflow was 400 km^3 (1986).

The water runoff is very unevenly distributed within a year: four months (from June to September) account for about 60–70% of the water runoff. The most water

Table 1. The structure of Lena River mouth area [1] (here and in Table 5, dash means lack of information)

Object	Staff gage, hydrometric section and its name	Distance, km	
		from zero of river length measurement (mouth)	from the river boundary of mouth area
Lena River mouth reach			
Lena River	Kyusyur V., river outlet	211	0
Lena River	Tit-Ary Settl., (delta head), river boundary of mouth area	49	162
Lena River	4.7 km upstream of Stolb island, delta	4.7	206
Olenek branch	Olnek gage, delta coastline	190	241
Olenek branch	Olimpiiskaya station	190	434
Bykov branch	Khabarov polar station, delta	0	214
Trofimov branch	Trofimov gage, delta coastline	128	216
Tumaty branch	Tumaty gage, delta coastline	145	224
Antipin branch	Sagyllakh-Ary polar station, delta coastline	6.0	336
Ispolatov branch	Malyshev polar station, delta	17	299
Nearshore zone of Lena R. mouth			
Buor-Khaya inlet	Muostakh Island	–	8
Tiksi Bay	Tiksi town	–	379

abundant months are June (36.4%) and July (20%) [12, 14, 19].

Over the period of many years, the character of the river water runoff variability within a year has not undergone any changes. The main water flow (more than 50%) enters the Trofimov branch [14, 19, 26]. The Bykov branch is characterized by an even distribution of water runoff shares during floods, summer and winter low-flow periods (28, 25, and 24%, respectively). The water runoff share in the Trofimov branch decreases with the water level growth from 70% during the winter low-flow period to 54% during floods. The share of the water runoff in the Olenek and Tumaty branches increases with the level rise from the low-flow period to the flood period [19, 26].

Over the period of 1934–1981, the runoff of the Lena River suspended sediments at the village of Kyusyur averaged 2400000 t/year [17]. The sediment runoff is even more unevenly distributed within a year than the water runoff. June and July are responsible for 59% and 42% of the annual sediment runoff, respectively. The Lena River water turbidity is insignificant; it averages 40 g/m^3 in the area of the village of Kyusyur, the maximum values reaching 400 g/m^3 during floods. The water turbidity is still lower in the delta, where it averages 21–24 g/m^3 [19]. The sediment runoff distribution among the delta branches is in proportion to the water runoff distribution [18].

Clogging phenomena, which result in water level rise, are typical of the Lena River mouth area [4, 5, 15]. The formation of jams as a result of the debacle of Arctic rivers may lead to hazardous phenomena such as the drastic water level rise and floods. The main features of these phenomena are the frequency of jams and water level rise caused by jams [4]. These features are most pronounced in the Lena River mouth area as compared to other lower reaches of Arctic rivers: the recurrence of jams is 100%, the water level rise caused by jams is 24.4 m [4].

The natural changes in the Lena River delta regime may be connected primarily with changes in the morphological structure of branches and with flow redistribution among them. One of the reasons of the anthropogenic impact on the delta hydrological regime is channel straightening for navigation purposes, including dredging in individual delta areas containing riffles and bars [16, 17, 25].

ANTHROPOGENIC FACTORS OF IMPACT ON THE LENA RIVER MOUTH AREA AND THEIR CONSEQUENCES

The vast and well-developed delta of the Lena River represents a powerful accumulator of different chemical substances, including pollutants. The sedimentation of large quantities of suspended and tractional particles and, hence, all the substances transported with them along the river is observed in its mouth area. The mixing of river and sea water results in the transition of various chemical substances from the dissolved state to the suspended state and vice versa [8, 11].

These processes contribute to the removal of different pollutants from the river water and prevent them from entering the sea. However, a certain amount of these substances remains in the aquatic environment of the mouth, in which their gradual accumulation occurs. The oxidation and complete transformation of pollutants in the Lena River mouth area are markedly slowed down in winter by the severe thermal regime and thick ice sheet, which hampers water aeration.

By its nature and duration, the external anthropogenic impact on the catchment basin of the mouth area is rather significant. The main sources of pollutants [1, 22] in this river reach are the following: the transfer (including transboundary) of pollutants in dustlike phase by air currents, the delivery by sea currents, the input with river flow from the Lena River basin, the operation of transport and engineering structures.

The most adverse effect on the aquatic environment condition in the river watershed within the river reach 1527 km long from the village of Tabaga to the mouth is exerted by wastewaters discharged from industrial water-using enterprises such as the Stock Company *Diamonds of Russia-Sakha*, Stock Navigation Company *Lena Steamship Line*, and Stock Company *Yakutskenergo* [7].

At present, the pollution of the aquatic environment and bottom sediments with oil products appears to be the most serious hazard to the aquatic ecosystem of the Lena River mouth area. Among all types of oil pollution that affect the area under study operational wastewater discharges from vessels are most significant.

Oil products occur not only in the form of a film on the mouth area water but also in the dissolved, emulsified, and absorbed (on hard particles of suspended substances and bottom sediments) forms. Bottom sediments represent a peculiar storage of pollutants, including oil products [23].

From the aforesaid, it should be expected that the formed type of pollution of the Lena River mouth area is of a combined nature. The stratification of industrial, domestic, and oil pollution occurs; this has a noticeable impact on the spatial and temporal variability of the aquatic environment composition.

SPATIAL AND TEMPORAL VARIABILITY OF AQUATIC ENVIRONMENT COMPOSITION IN THE LEVA RIVER MOUTH AREA

To study the spatial and temporal variability of aquatic environment component composition, the use was made of the long-term systematic hydrochemical information from the State Service for Environmental Condition Observation [6, 7].

The chemical composition of the aquatic environment of river mouth areas is formed under the influence of the following factors [22]: the type of local and regional, including transboundary, distribution of pollutants; the sorption of pollutants by river ice from the atmosphere and by the river proper during its freezing period; bioaccumulation of many pollutants and their involvement in food chains of biocenoses.

The total impact of pollutants is felt throughout the river length down to the outlets. Therefore, the transfer of pollutants by river should be considered as a source of local and regional distribution of pollutants, which is now a determining factor of variability of the hydrochemical regime not only in river lower reaches but also in the estuaries and coastal zones of seawater areas.

N- and P-containing Compounds

The analysis of long-term hydrochemical information (provided by the State Service for Environmental Condition Observation) concerning the content of mineral forms of N and P in the aquatic environment of the Lena River mouth area revealed the high spatial and temporal variability in their concentrations (Tables 2–4).

The implemented comparison assessment of concentration fluctuation ranges in biogenic element compounds over the long-term period of 1980–2007 showed that the maximum values of ranges differed considerably at the river outlet (the village of Kyusyur), in the delta (the polar station of Khabarov), and in the Neelov Bay (the town of Tiksi). For example, the range of fluctuations of ammonium N concentrations near the village of Kyusyur (below detection limit (b.d.l.)–0.64 mg N/l) was wider than in the delta (b.d.l.–0. 41 mg N/l) and in the Neelov Bay (0.01–0.15 mg N/l).

The observations show that the concentrations of ammonium N and P of phosphates tend to decrease from the outlet to the bay, while the concentration of nitrate N tends to increase. The concentration of nitrate N varied from b.d.l. to 0.40 mg N/l at the village of Kyusyur, from b.d.l. to 0.30 mg N/l in the delta, and from 0.02 to 0.54 mg N/l in the Neelov Bay. Maximum concentrations of nitrite N (0.048 mg N/l) and total P (0.394 mg P/l) were recorded in the delta of the mouth area.

During 1980–1994 [9], observations over the spatial variability of ammonium N content in the aquatic environment of the nearshore zone of the river mouth were carried out; they revealed more considerable differences between the inlet of Buor-Khaya (b.d.l.–0.01 mg N/l) and the Tiksi Bay (b.d.l.–0.46 mg N/l). The variability within a year of maximum concentrations of N- and P-containing compounds radically changes over the Lena River mouth area. According to the authors' information, accumulation of ammonium N was recorded in May–June at the river outlet, in May–August in the delta, and in October in the Neelov Bay.

As shown above [2, 3, 22], the disturbance of the natural seasonal variability and spatial and temporal nonuniformity of concentrations of biogenic elements in the aquatic environment is caused by the prevailing role of the anthropogenic factor in the formation of their regime.

Table 2. Variability of composition parameters of aquatic environment at river outlet near Kyusyur village (1980–2007) (here and in Tables 3 and 4 b.d.l. means below detection limit; the figures in parentheses are detection frequences)

Ingredients (MPC), mg/l	Range of concentration fluctuation, mg/l		Exceedance factor of maximum concentrations	
	total	MOM	in terms of MPC	in terms of maximum MOM values
Sum of ions (1000)	27.5–363	50.8–148 (70)	<1	2.5
Suspended substances	b.d.l.–270	b.d.l.–19.6 (80)	<1	14
Silicic acid	0.20–8.00	0.20– 3.00 (88)	<1	2.7
Mg compounds (40)	0.10–30.0	0.10– 10.0 (93)	<1	3.0
Chlorides (300)	0.60–90.0	0.60–20.2 (79)	<1	4.5
Sulphates (100)	0.90–67.3	0.90–20.0 (66)	<1	3.4
Dissolved oxygen	6.20–16.3	10.0–14.0 (76)		
Readily oxidized organic substances, by BOD_5 (2.0)	0.20–7.10	1.05–2.50 (60)	3.6	2.8
Bichromate oxidizability	0.50–63.4	0.50–29.8 (93)	<1	2.1
ammonium N (0.39)	0.01–0.64	0.01–0.10 (80)	1.6	6.4
nitrite N (0.020)	b.d.l.–0.022	b.d.l.–0.005 (84)	1.1	4.4
nitrates (9.0)	b.d.l.–0.40	b.d.l.–0.05 (70)	<1	8.0
phosphate P (0.20)	b.d.l.–0.047	b.d.l.–0.010 (83)	<1	4.7
total P	b.d.l.–0.146	b.d.l.–0.030 (85)	<1	4.9
Phenols (0.001)	b.d.l.–0.040	b.d.l.–0.005 (82)	40.0	8.0
Oil products (0.05)	b.d.l.–0.49	b.d.l.–0.10 (80)	10.0	5.0
Synthetic surfactants (0.10)	b.d.l.–0.07	b.d.l.–0.02 (75)	<1	3.5
Fe total (0.10)	0.01–2.07	0.01–0.50 (66)	21.0	4.1
Cu compounds (0.001)	b.d.l.–0.043	b.d.l.–0.010 (69)	43.0	4.3
Zn compounds (0.010)	b.d.l.–0.059	b.d.l.–0.020 (72)	6.0	3.0

The period under study made it possible to clearly reveal the tendency for regular accumulation of ammonium N in the aquatic environment up to the concentrations exceeding the maximum permissible environmental concentrations (MPEC) conventionally assumed for eutrophic water bodies [24]. The main reason for such transformation of the regime of N- and P-containing compounds is in the predominance of the processes of mineralization of incoming organic substances over the processes of consumption of biogenic elements.

Prevailing Pollutants

Taking into account the important role of anthropogenic factor in the formation of the aquatic environment composition of the ecosystem as well as the system-forming parameters of the state of its abiotic component, priority is given to the chemical elements whose concentrations exceed the maximum permissible concentration (MPC) with a sufficient occurrence; in addition to this, new ”human-induced natural background” (determined by the interval of most often met (MOM) values of concentrations) is formed for these elements [21].

The maximum MPC exceedance factor (Tables 2–4) in the studied reaches of the Lena River mouth area was 40 for phenols and 43 for Cu compounds at the river outlet; 25 for oil products, 29 for Cu compounds and 32 for Fe compounds at the delta head near the polar station of Khabarov.

A tendency for a decrease in the maximum MPC exceedance factor in the compounds listed above is observed in the Neelov Bay near the town of Tiksi; this area also features the tendency for periodic accumulation in the aquatic environment of chlorides up to 3.5 MPC, nitrite N up to 3.1 MPC, the sum of ions up to 1.9 MPC, and Mg compounds up to 1.7 MPC.

The accumulation of compounds of biogenic elements and prevailing pollutants, the concentrations of which in the aquatic environment exceed the established MPC, results in the formation of a new, anthropogenically affected natural background for these

Table 3. Variability of composition parameters of aquatic environment at delta head near polar station of Khabarov (1980–2007)

Ingredients (MPC), mg/l	Range of concentration fluctuation, mg/l		Exceedance factor of maximum concentrations	
	total	MOM	in terms of MPC	in terms of maximum MOM values
Sum of ions (1000)	16.0–496	52.3–148 (60)	<1	3.4
Sum of ions (1000)	b.d.l.–369	b.d.l.–20.0 (81)	<1	18.0
Silicic acid	0.10–11.5	0.10–4.00 (94)	<1	2.9
Mg compounds (40)	0.20–32.5	0.20–10.0 (78)	<1	3.3
Chlorides (300)	4.30–227	4.30–94.5 (96)	<1	2.4
Sulphates (100)	0.30–107	0.30–39.8 (82)	1.1	2.7
Dissolved oxygen	3.43–18.8	9.02–13.0 (73)		
Readily oxidized organic substances, by BOD_5 (2.0)	0.05–10.4	0.51–1.50 (61)	5.2	6.9
Bichromate oxidizability	0.90–186	0.90–2.8 (94)	<1	6.2
ammonium N (0.39)	b.d.l.–0.41	0.01–0.05 (64)	1.1	8.2
nitrite N (0.020)	b.d.l.–0.048	b.d.l.–0.005 (71)	2.4	9.6
nitrates (9.0)	b.d.l.–0.30	b.d.l.–0.005 (63)	<1	6.0
phosphate P (0.20)	b.d.l.–0.080	b.d.l.–0.010 (65)	<1	8.0
total P	b.d.l.–0.394	b.d.l.–0.030 (78)	<1	13.0
Phenols (0.001)	b.d.l.–0.015	b.d.l.–0.004 (89)	15.0	3.8
Oil products (0.05)	b.d.l.–1.26	b.d.l.–0.10 (85)	25.0	13.0
Synthetic surfactants (0.10)	b.d.l.–0.14	b.d.l. –0.03 (91)	1.4	4.6
Fe total (0.10)	0.01–3.16	0.01–0.50 (90)	31.6	6.3
Cu compounds (0.001)	b.d.l.–0.029	b.d.l.–0.009 (75)	29.0	3.2
Zn compounds (0.010)	b.d.l.–0.054	b.d.l.–0.014 (74)	5.4	3.9

indices. In this case, the natural environmental condition of the mouth area becomes disturbed; this, in turn, may cause changes not only in the trophic status of the aquatic ecosystem but also in its ecological capacity.

The comparison assessment of the anthropogenically affected natural background over the period under study revealed the variability in accumulation of studied ingredients in the aquatic environment within the area from the river outlet to the Neelov Bay. The exceedance factor of the maximum values of the total range of fluctuation of concentrations and most often met (MOM) concentration values increased from 2.5 to 15 times for the sum of ions, from 2.7 to 10 times for Mg compounds, from 4.5 to 63 times for chlorides, and from 3.5 to 11 times for P phosphates; in the direction to the delta head, the exceedance factor increased up to 18 times for suspended substances and up to 13 times for total P (Tables 2–4).

Many of the compounds listed above should be considered as prevailing pollutants in the Lena River mouth area. The main regularities in the variability of the aquatic environment composition in this river reach are as follows: the spatial nonuniformity of variation ranges in concentrations of particular chemical compounds; a noticeable variability of fluctuation ranges in the concentrations of ammonium N, oil products, and synthetic surfactants; the high degree of pollution of all areas under study with oil products (5.2–25 MPC), Cu compounds (16–43 MPC), and phenols (8–40 MPC); typical dependence of the concentration of phenols on hydrological features.

At the beginning of spring flood, the concentration of phenols does not exceed 0.001 mg/l. However, the concentration of phenols increases with increasing flow. This is because large quantities of organic substances, including residues of conifers, are washed off the watershed [8]. During floods and high-water periods, the concentration of phenols often exceeded 0.010 mg/l and it is still higher near wastewater outlets. The content of phenols in the areas of Buor-Khaya Bay more distant from the seaport does not exceed 0.002 mg/l [8].

ANTHROPOGENIC LOAD ON THE LENA RIVER MOUTH AREA

The Lena River mouth area is subject to external natural and anthropogenic impact, including the input of considerable amounts of pollutants with the river

Table 4. Variability of composition parameters of aquatic environment in Neelov Bay (town of Tiksi) over the period of 1993–2000

Ingredients (MPC), mg/l	Range of concentration fluctuation, mg/l		Exceedance factor of maximum concentrations	
	total	MOM	in terms of MPC	in terms of maximum MOM values
Sum of ions (1000)	35.5–1860	35.5–126 (62)	1.9	15.0
Suspended substances	1.2–110	1.2–18.9 (70)	<1	5.8
Silicic acid	0.40–8.4	0.50–2.9 (73)	<1	2.9
Mg compounds (40)	0.50–70.0	2.1–6.7 (65)	1.7	10.0
Chlorides (300)	3.1–1050	3.1–16.8 (62)	3.5	63.0
Sulphates (100)	6.3–64.2	6.3–27.2 (68)	<1	2.4
Dissolved oxygen	5.74–14.5	8.1–12.2 (85)		
Readily oxidized organic substances, by BOD_5 (2.0)	0.10–5.95	0.41–1.46 (68)	3.0	4.1
Bichromate oxidizability	7.1–47.5	11.0–29.8 (71)	<1	1.6
ammonium N (0.39)	0.01–0.15	0.01–0.10 (85)	<1	1.5
nitrite N (0.020)	b.d.l.–0.062	0.001–0.016 (82)	3.1	3.9
nitrates (9.0)	0.02–0.54	0.02–0.10 (82)	<1	5.4
phosphate P (0.20)	b.d.l.–0.098	0.001–0.009 (56)	<1	11.0
total P	0.003–0.100	0.005–0.040 (82)	<1	2.5
Phenols (0.001)	b.d.l.–0.008	0.001–0.003 (68)	8.0	2.7
Oil products (0.05)	b.d.l.–0.26	0.04–0.10 (65)	5.2	2.6
Synthetic surfactants (0.10)	b.d.l.–0.06	0.01–0.03 (76)	<1	2.0
Fe total (0.10)	0.03–1.28	0.12–0.81 (76)	13	1.6
Cu compounds (0.001)	b.d.l.–0.013	0.001–0.005 (79)	13	2.6
Zn compounds (0.010)	b.d.l.–0.034	0.007–0.021 (56)	3.4	1.6

flow. Therefore, the river inflow of pollutants is a factor determining the variability of the hydrochemical regime of river mouth areas [2, 3, 22]. The calculation and analysis of data on long-term (1980–2007) and seasonal changes in the inflow of dissolved chemical substances to the river outlet (the village of Kyusyur) and into the Bykov branch to the delta head (the polar station of Khabarov) have shown that the physical transport of numerous dissolved substances, including pollutants, along the river dominates over the processes of their chemical and biological transformation and noticeable amounts of pollutants outflow into the mouth area and the delta.

The comparison analysis of the input of prevailing pollutants shows that the river outlet and the delta head are characterized by the maximum input of pollutants containing Si compounds (up to 2284000 and 2652000 t/year), readily oxidized organic substances (up to 1615000 and 1137000 t/year), and Fe compounds (up to 685000 and 293000 t/year) (Tables 5 and 6).

Over the periods under study, the mean values of input of compounds listed above remain high enough in the new millenium. In recent years, the inflow of P compounds tends to increase in the same areas. The increase in the inflow of oil products occurs at the river outlet against the background of an insignificant decrease in the input of phenols, and Cu and Fe compounds. An increase in the input of mineral forms of N is recorded in the delta of the mouth area against the background of a decrease in the input of phenols, oil products, and Zn and Fe compounds (Tables 5 and 6).

When the range of fluctuation of the mean long-term input of chemical substances is compared with MPC volumes (Table 7), it becomes apparent that the maximum values of the input of prevailing pollutants exceed the allowable values for phenols 3.5–8.5 times at the river outlet and 2.3-4.1 times in the delta, the allowable values for Fe compounds, 4.6–12.8 and 2.4–5.8 times, and the allowable values for Cu compounds, 4.5–13.5 and 4.3–14.8 times, respectively.

The anthropogenic load on the river mouth area can be assessed not only by the input of pollutants but also by their modulus of input. The calculation of the long-term variability of the modulus of input for ammonium N, readily oxidized organic substances,

Table 5. Temporal variability (1980–2007) of the input of prevailing chemical substances to the Lena River outlet near Kyusyur village (here and in Table 6, *n* means the number of years, for which data on input are available)

Ingredient	Input of chemical substances, 1000 t/year											
	total range of fluctuation	mean long-term	range of fluctuation in 1980–1984	average for the period	range of fluctuation in 1985–1989	average for the period	range of fluctuation in 1990–1994	average for the period	range of fluctuation in 1995–1999	average for the period	range of fluctuation in 2000–2007	average for the period
Ammonium N	10.1–98.0	40.9	61.7–73.8 $n=2$	66.7	23.68–72.0	51.0	10.1–62.7	27.3	10.2–98.0	41.1	20.2–49.1	33.2
Nitrite N	0.43–4.46	1.95	Insufficient data ($n = 6$): 0.43–2.78; average 1.44								1.07–4.46	2.46
Nitrate N	13.7–56.0	26.6	13.7–24.1 $n=2$	18.9	13.7–56.0	35.9	15.2–32.1	23.6	18.4–43.7	28.7	16.1–38.8	23.3
Phosphate P	1.20–7.90	3.71	0.31 $n=1$	–	1.2–7.90	3.63	1.5–6.42	3.93	1.8–4.24	3.28	2.67–5.36	3.88
Total P	3.67–33.3	11.0	7.85 $n=1$	–	4.17–16.3	7.68	6.08–11.8	8.50	3.67–11.4	8.43	8.21–20.0	18.22
Silicic acid	529–2284	1095	543.9 $n=1$	–	529–1500	919	803–1052	943	671–2284	1293	549–1990	1234
Readily oxidizable organic substances, by BOD_5	350–1615	1112	350–614.9	1190.3	612.0–1164.7	920.1	708.5–802.5	767.3	1035.2–1395.4	1208.9	1144.7–1621.1	1327.4
Phenols	0.22–4.56	1.89	0.22–1.17	0.76	0.88–4.37	2.31	1.5–4.56	2.97	1.02–2.65	2.05	1.07–1.67	1.39
Oil products	2.54–102	40.5	26.2–35.9	34.7	12.0–39.5	23.2	2.54–48.2	25.4	15.3–102.1	50.3	23.6–80.8	54.8
Fe (total)	15.7 – 685	246	15.7–685	266.4	180.8–355	271	129.5–308.5	242.7	53.5–424.0	288.6	85.8–385	187.4
Cu compounds	0.76– 7.29	2.44	2.72–4.22	3.38	0.76–2.84	1.67	1.15–5.31	2.39	1.37–7.29	3.20	1.71–3.36	2.09
Zn compounds	0.75–15.5	5.91	6.28–15.5	11.1	2.56–9.72	5.68	0.75–10.1	6.00	2.45–12.4	5.60	1.93–7.75	4.26
Water runoff, km^3	400–728	536.7	523– 595	566	400–728	538	482–535	510	486–612	542	483–646	535

Table 6. Temporal variability (1980–2007) of input of prevailing chemical substances to the delta head of the Lena River mouth area near polar station of Khabarov

Ingredient	Input of chemical substances, 1000 t/year											
	total range of fluctua-tion	mean long-term	range of fluctuation in 1980–1984	average for the period	range of fluctuation in 1985–1989	average for the period	range of fluctuation in 1990–1994	average for the period	range of fluctuation in 1995–1999	average for the period	range of fluctuation in 2000–2007	average for the period
Ammonium N	0–55.4	28.4	0–43.1	20.5	14.2–47.8	30.7	11.4–22.8	16.2	19.7–55.4	36.7	21.8–53.0	33.3
Nitrite N	0–5.02	2.43	0–3.61	2.47	0.79–2.28	1.56	0.47–2.07	1.26	0.49–4.87	2.74	2.13–5.02	3.47
Nitrate N	5.90–78.5	34.7	12.9–61.8	41.6	24.0–36.9	30.5	22.7–31.9	28.0	5.9–43.4	32.7	19.3–78.5	39.4
Phosphate P	0.97–27.3	6.53	2.79–27.3	11.0	1.43–8.73	3.93	0.97–9.10	3.81	3.73–7.49	5.85	3.62–11.1	8.03
Total P	1.86–73.4	18.61	6.28–32.3	18.3	4.76–12.7	7.98	1.86–13.4	5.92	8.53–40.1	16.6	9.13–73.4	33.3
Silicic acid	561–2652	1190	853–1046	937.5	561–1522	963	1067–1298	1175	563–2459	1391	639–2652	1344
Readily oxidizable organic substances, by BOD_5	269–1137	575.1	837–1137	931	401–703	540	267–498	392	327–686	516	422–684.5	570
Phenols	0.51–2.07	1.13	0.52–1.08	0.71	0.67–1.91	1.11	0.93–2.07	1.36	0.91–197	1.47	0.51–1.26	0.93
Oil products	17.3–72.4	38.5	17.3–46.4	30.5	17.5–51.2	28.3	22.7–72.4	58.4	26.1–63.0	38.3	25.9–53.2	39.1
Fe (total)	50.1–293	120.1	62.0–240.6	176	50.1–293.0	168.8	71.4–106.7	85.4	54.9–255.8	105.8	58.7–162.5	92.2
Cu compounds	0.77–7.55	2.14	3.76–7.55 $n=2$	5.65	0.88–3.82	2.48	1.10–3.99	1.95	0.77–2.09	1.53	1.16–2.24	1.55
Zn compounds	2.03–12.0	5.08	6.90–11.7	8.79	3.39–11.4	6.39	2.59–12.0	4.85	3.34–7.03	5.15	2.03–6.57	2.98
Water runoff, km^3	334–637	507	515–539	523.5	334–637	458	464–517	482	454–609	523	435–628	534

Table 7. Mean long-term and allowable in terms of MPC input of prevailing pollutants to the Lena River mouth area

Ingredients (MPC), mg/l	Input of chemical substances, thous. t/year							
	Kyusyur V.				Khabarov polar station			
	mean long-term	allowable in terms of MPC	exceedance factor		mean long-term	allowable in terms of MPC	exceedance factor	
			mean long-term	maximum by mean annual			mean long-term	maximum by mean annual
ammonium N (0.39)	41.0	219	0.19	0.46	29.8	197	0.15	0.28
nitrite N (0.02)	1.95	10.8	0.18	0.42	2.37	10.1	0.23	0.50
Readily oxidizable organic substances, by BOD_5 (2.0)	1112	1076	1.03	1.5	578	1012	0.57	1.1
Phenols (0.001)	1.89	0.54	3.5	8.5	1.15	0.51	2.3	4.1
Oil products (0.05)	40.5	26.9	1.5	3.8	39.0	25.3	1.5	2.9
Fe compounds (0.10)	246	53.8	4.6	12.8	122	50.6	2.4	5.8
Cu compounds (0.001)	2.44	0.54	4.5	13.5	2.18	0.51	4.3	14.8
Zn compounds (0.010)	5.91	5.38	1.1	2.9	5.20	5.06	1.03	2.4

Table 8. Classification of anthropogenic load by the modulus of pollutant input [23]

Anthropogenic load	Range of maximum values of modulus of input, t/km^2/year		
	ammonium N	readily oxidizable organic substances (by BOD_5)	oil products
Low	up to 0.05	up to 0.5	up to 0.05
Moderate	0.06–0.10	0.51–1.0	0.06–0.10
Critical	0.11–0.20	1.1–1.5	0.11–0.30
High	0.21–0.30	1.6–2.0	0.31–0.50
Very high	0.31–0.60	2.1–3.0	0.51–1.0
Extremely high	>0.60	>3.0	>1.0

and oil products and their comparison with the anthropogenic load classification (Table 8) worked out by the authors [22] makes it possible to assess the level of anthropogenic load. With regard to this index, the ecosystem of the Lena River mouth area experiences low anthropogenic load at the river outlet and in the delta (Table 9).

Under this anthropogenic load, the Lena River mouth area is being formed as an ecosystem, which differs radically from the river and has its own hydrological, hydrochemical, and hydrobiological features.

CONCLUSIONS

The growing anthropogenic impact leads to gradual transformation of the hydrological and hydrochemical conditions of the aquatic environment of the Lena River mouth area. Adverse effects primarily arise because of the input of considerable amounts of chemical pollutants with the river flow and an increase in sediment and thermal runoff. Under the present anthropogenic impact, the river mouth area is functioning as a geochemical barrier for considerable quantities of pollutants, which come from the local watershed and in the course of transit movement.

Table 9. Anthropogenic load in terms of prevailing pollutants in the Lena River mouth area

Ingredient	Parameter	Mouth river reach	
		Kyusyur V.	Khabarov polar station
		watershed area	
		2430000 km^2	2460000 km^2
ammonium N	Range of maximum input values, thous t/year	61.7–98.0	50.2–55.4
	Range of maximum values of modulus of input, t/km^2 year	0.025–0.040	0.020–0.022
	Anthropogenic load	Low	Low
Readily oxidizable organic substances (by BOD_5)	Range of maximum input values, thous t/year	126–1615	837–1137
	Range of maximum values of modulus of input, t/km^2 year	0.520–0.667	0.34–0.46
	Anthropogenic load	Moderate	Low
Oil products	Range of maximum input values, thous t/year	77.5–102	63.0–72.4
	Range of maximum values of modulus of input, t/km^2 year	0.025–0.042	0.026–0.029
	Anthropogenic load	Low	Low

It is found that the mean annual input of phenols, Cu and Fe compounds at the river outlet (the village of Kyusyur) may be tens of times higher than the MPC.

This anthropogenic load on the mouth area ecosystem enhances and speeds up the transformation of its abiotic component as a result of changes in the hydrochemical characteristics, such as ion composition, mineralization, readily oxidized organic substances, and dissolved oxygen in water, as well as a result of accumulation of mineral forms of N and P and pollutants in water, which at high concentrations are able to noticeably change the ecosystem trophicity and have a toxic effect on the biota.

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