ASSESSMENT OF THE DISCHARGE OF SOME CHEMICAL SUBSTANCES FROM THE AMUR INTO THE SEAS OF JAPAN AND OKHOTSK

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The Amur river today is one of the most polluted rivers in Russia due to a complex impact of different natural and anthropogenic processes in its basin that influence river water quality. Multi-component disturbance of natural landscapes in the drainage area, industrial, agricultural and community wastewater discharge into the river from Russian and China coupled with river regime changes accelerated the formation of a disastrous ecological situation in Priamurje. Most intensive changes of water quality take place in the Lower Amur [2] mostly caused by the anthropogenic pollution of the Sungari river.

Still mixing pattern of water from the Amur and Sungari in different parts of the Amur varies, thus causing uneven distribution of various chemical substances along and across the river. Seasonal changes of chemical discharge ion both rivers are also registered. All these factors make it rather difficult to assess the total volume of various chemical substances discharge from the Amur into the Seas of Okhotsk and Japan.

The Institute of Water and Ecology Problems, FEB RAS (IWEP) carried out river water quality studies in the Lower Amur from Khabarovsk to Bogorodskoe during of the seasons of 2005 and 2006. The main sampling took place near the villages Nizhneleninskoe, Petrovskoe, Nizhnespasskoe, Bogorodskoe, the cities of Khabarovsk and Komsomolsk-on-Amur and the low reaches of the Amgun river.

Water samples were analyzed in the laboratories of IWEP FEB RAS, The Analytic Center of the Institute of Tectonics and Geophysics, FEB RAS, research institutes in Ufa and Obninsk cities. Trace metals were analyzed with ICP-MS Elan DRC II Perkin Elmer (USA) mass spectrometer with inductively coupled plasma.

The data collected and combined with previous data serve a good basis for deep analysis of the present state and conditions that form Amur water quality, which, in its turn, determines the current state of freshwater, watershed and seawater ecosystems.

The Amur run-off is formed in a vast area (1 855 000 km^2), characterized with diverse natural conditions, which determine a complex background for water chemical composition. Significant run-off irregularities between the seasons and in perennial regime produce high dynamics of major indicators of water qualitative characteristics. Economic activities in the river basin also have a big impact on water quality in the Amur.

The Amur is classified as a Far Eastern river type with a prevailing precipitation-formed run-off as its specific feature. The annual share of precipitation in run-off formation reaches 90% and provides water abundance in a warm period. Snow source is of secondary importance and spring high water is observed at the end of April and the beginning of May.

Average perennial water discharge in the river mouth is 10 900 m^3/sec. Maximal registered discharge near Khabarovsk was 40 000 m^3/sec (September 1897) and minimal discharge was 153 m^3/sec (March 1922). Within the year discharge rate greatly fluctuates. In the cold period (November – March) it is minimal. In spring owing to snow melting the water level rises. The lowest water level in non-freezing period is usually registered at the beginning of summer. Maximal levels and discharge is observed in summer-autumn time (July – October), owing to frequent rain storms brought by typhoons and cyclones from East-Asian seas [5].

Morphological specifics of the riverbed of the Lower Amur passage (1 200 km from the Sungary juncture to the river estuary) include current directed accumulation. Lots of narrowings and expansions here determine riverbed structure and dynamics [3]. In wide valley parts the stream is split into numerous big and small sub-streams, spreading in a fan-like pattern down the river and forming extremely complicated hydrographic drainage. Wide sub-streams (0.8-1.5 km) form a river drainage frame, rather stable in time. These sub-streams split and merge with dozens smaller sub-streams to form permanent or temporary existing streams.

In the mountainous areas the Amur valley becomes narrow and steep mountainous slopes limit riverbed deformation development. The river there has a single stream with gentle meanders. Still due to substantial alluvial flows and their intensive sedimentation the stream dynamic axis often changes its position, thus changing the location of the waterway.

The Lower Amur has three big tributaries: the Ussuri, 897 km long and having drainage area of 193 000 km^2, the Tunguska River, 544 km long and having drainage area of 30 200 km^2, the Amgun River, 723 km long and having drainage area of 193 000 km^2.

The Amur is characterized with significant run-off fluctuations between the years. In some years the river water content may be small, medium and large. Water content differences are more evident in summer. In winter the river water content is more stable. In recent 10 years the smallest water content was observed in 2002, medium content was in 2004 and the largest was in 1998. In 2006 it can be described as close to medium.

In 2005-2006 winter period low water level fluctuated near Khabarovsk from –127 to – 150 cm. In spring 2006 a small flood tide was observed on the Amur, which in May reached 197 cm. A bigger flood happen later and had two peaks (June 30 – 327 cm and August 14 – 342 cm). Summer low water period was not long (7-10 days) with minimal water levels of 15 cm. A stable water level decrease up to – 92 cm was observed in autumn before river freezing began (Fig. 1).

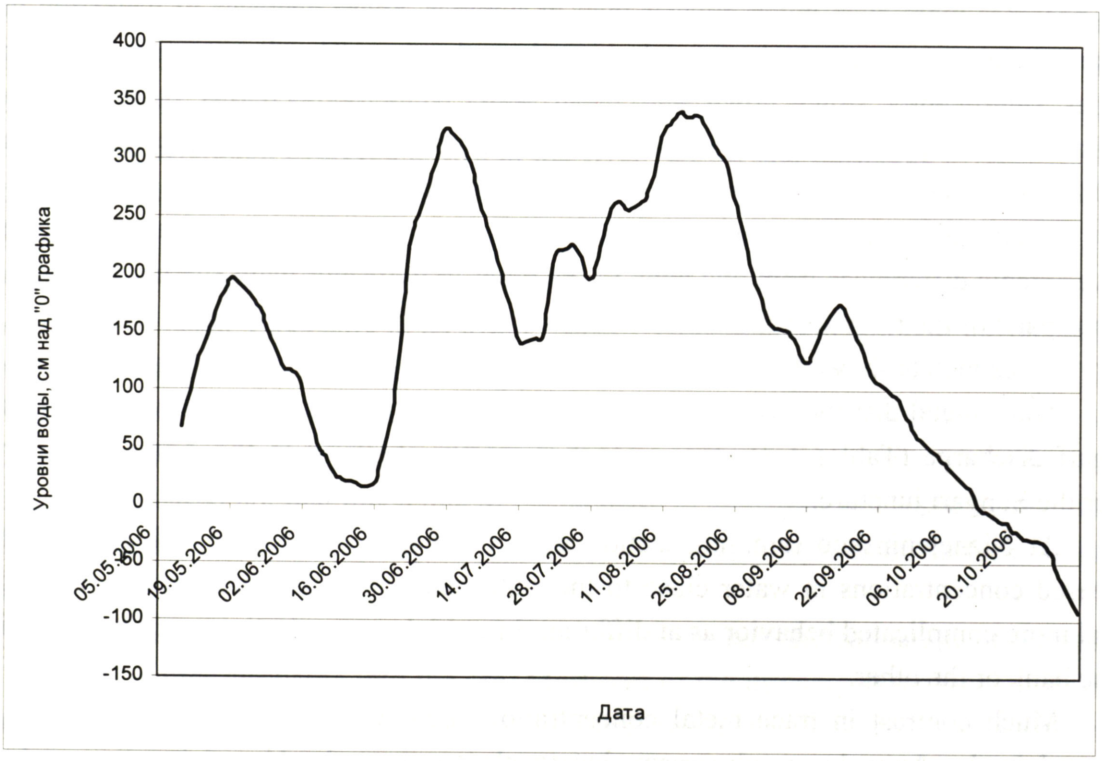

Fig. 1. Amur water levels near Khabarovsk in summer 2006.

The Amur near Khabarovsk has very specific and complicated conditions, which determine mixing of water masses that come from upstream regions. There are several main factors that form chemical distribution pattern across and along the stream. The first one is that the Amur here has many sub-streams and water run-off distribution between the sub-streams fluctuates in volume in different phases of water regime.

Secondly, The Ussuri River joins one of the Amur sub-streams upper Khabarovsk. Ussuri water mixes with Amur water in two places. The first time it partially mixes at the juncture of the Ussuri and the sub-stream and the second time it mixes with the Amur mainstream. Depending on water abundance in the river the rate and scope of water mixing changes significantly.

The third factor is that the Amur riverbed from the Sungari juncture to Khabarovsk has strongly marked specific morphological features as the river width exceeds (hundred times) its depth. Due to intensive stream turbulence and rapid vertical mixing of water masses (from the surface to the bottom), mixing of water across the river proceeds extremely slowly. Besides, in summer time this mixing process is even more slowed due to the appearance of extensive net of long and water abundant sub-streams.

Perennial regime of the Amur run-off is characterized with well-marked interchange of low and high water content periods of 8-15 years. Last 10 years the Amur water content is low. Besides, in the summers of 2000, 2001 and 2003 the river water level was extremely low and record-breaking.

In winter special conditions are created. Due to a substantial decrease of water levels and deep freezing of several sub-streams the distribution of chemical substances across the river becomes more even much quicker than in summer. Sharp decrease of water run-off in winter accelerates water velocity irregularities along the river. The river current in long river reaches significantly slows down and mean water velocity decreases more than twice compared to summer rates. Thus, in December 2005 and January 2006 it fluctuated from 30 to 50 km/day, whereas in summer it is usually 70-80 km/day.

Detail studies of cross section distribution of the main hydrochemical characteristics showed stable differences from one bank to the other in the Amur main stream. Moreover, in various parts of the river near Khabarovsk they were of different character.

Trace metals showed most uneven distribution in cross section.

Trace metal distribution revealed a certain regularity resulting from evident impact of Sungari discharge (Tables 1-3). This impact is mostly observed in the Amur main stream lower the Sungari juncture.

At Niznеleninskoe sampling station most trace metals (Cu, Zn, Cd, Hg, Pb) have increased concentrations in water close to the right bank or in the river middle. Cr and As reveal more complicated behavior as at different times high concentrations are observed either at one bank or the other.

Much contrast in trace metal concentrations between the right and left banks was observed in the Amurskaya sub-stream due to closeness to the Ussuri juncture and poor mixing of Ussuri and Amur waters. Higher trace metal concentrations in summer were observed close to the left bank the Amurskaya sub-stream, where Amur water dominates. But some metal contents (Cu, Zn, Pb) in spring and at the beginning of summer were significant at the right bank of the sub-stream.

Seasonal fluctuations of trace metal content in Amur water were observed. Relatively low quantitative records were registered in May and September and much higher records were in June that may be explained with the surface run-off in the drainage basin resulting from precipitation.

Average perennial Amur run-off is 369.1 km^3 [4]. Its maximum of 459 km^3 in the observation period was recorded in 1985 and its minimum record was 250.8 km^3 in 1979. Thus, maximal run-off exceeds the minimal one in 1.8 times.

Perennial regime of the Amur run-off is characterized with strongly marked interchange of low and high water content periods, which last 8-15 years. High water content periods occurred in 1890-ies, 1910-teens, 1930-ies, 1950-ies and 1980-ies. Moreover, water content gradually increased from period to period and reached its maximum in the 1950-ies, when disastrous floods caused severe damage to regional economy. The last high water content period in1980-ies was not severe compared to previous ones due to significant anthropogenic impact of recently constructed hydropower energy facilities and increased consumption of water for industrial and agricultural use. Still, water levels at maximal floods in this cycle (1984 and 1991) nearly reached their historic maximum.

Low water content periods occurred in 1920-ies, 1940-ies, 1970-ies and 1990-2000. In the last low water cycle a slight decrease of the run-off was observed, which is probably also caused by the anthropogenic impact. Extremely low levels were registered in summer in 2000, 2001 and 2002 and they were very close to record-breaking in all the observation period.

All these observations indicate an evident increase of the degree of contrast in main hydrological characteristic indicators, such as water levels, run-off, turbidity and suspended matter discharge. Amur hydrological regime changes mostly due to anthropogenic impact result in the acceleration of irregularities in the river run off and discharge of dissolved and solid substances into the Okhotsk and Japan Seas.

Generally, it is estimated that the Amur water content has increased by 10-12% in 100-year period of observations. It is explained by the increase of atmospheric precipitation in the Amur River basin, especially in its lower reaches. Annual precipitation in the cold season (November – March) has increased nearly twice in recent 112 years (from 1891 till 2003). Warm season increase (April – October) is estimated as 1.2 times [1]. Total moistening of the Amur basin territory in the period of observations has increased by 31%. The Amur water content has increased not that much due to the increase of evaporation, caused by the average annual temperature rise in the region, but due to the consumption of surface water for economic development purposes.

Numerous natural and anthropogenic factors influence the formation of terrigenous and chemical matter discharge into the sea. Most part of the discharged terrigenous matter is accumulated in the Middle Amur. The biggest tributaries Zeya, Bureya, Sungari and Ussuri join the Amur in this passage of less than 1 000 km. Their accumulate 65% of the Amur run off and over 90% of suspended matter discharge. Unconsolidated clayey sediments, abundant in the basing of these tributaries and highly intensive riverbed processes cause significant suspended sediment discharge and increased water turbidity (up to 400-500 μg/l) within the Amur middle and lower reaches.

Suspended sediment discharge from the tributaries into the Amur mainstream has general geographic regularities. In the Russian part of the river basin its module fluctuates from 8 to 32 tons/km^2 per year with maximum volumes in the Zeya-Bureya plain (20 – 32 tons/km^2). Suspended sediments bring along significant amount of pollutants, especially trace metals and organic substances.

A general correlation between perennial sediment discharge and river water run off is observed. In 1960-ies was a period of increased sediment discharge, changed by the period of low sediment discharge in 1970-ies. In 1980-ies again the increase in sediment discharge was quite evident, and in 1990-ies volumes of sediment discharge were relatively small. This period is being continued now.

The following regularity in suspended sediment discharge along the river towards its lower reaches has been observed: average size of suspended particles becomes smaller. The share of particles less than 0.005 mm in size near Khabarovsk is 20% of the total amount of suspended matter, whereas near Bogorodskoe this share grows to 60%.

Permafrost rocks, widely spread in the northern part of the Amur basin, much determine the Amur chemical discharge. In the mountainous regions its layer can be 300 m thick, having temperature -5^0C. Such rocks significantly limit the underground flow and thus the flow of dissolved substances. Bogs and swampy areas are the other factors that influence dissolved matter discharge.

Amur run off irregularities, especially in summer cause significant fluctuations in organic matter discharge. In time of extremely summer low water, observed in 200 and 2001 vegetation started to grow at the bottom of dried lakes and sub-streams. Then later they were filled with water and a great amount of decomposed biomass was discharged from those lakes and sub-streams into the river main stream. This discharge could be compared to a instantaneous release.

The total volume of organic matter discharge from the Amur into the Okhotsk and Japan Seas is estimated 5.5 million tons [6]. Most of the organic matter amount is discharged in the second half of the warm period, predominantly in the July – October period.

Total dissolved matter discharge from the Amur into the Okhotsk and Japan Seas is 18.3 million tons per year [6]. The following ions compose the biggest share of this discharge (in million tons per year): calcium - 2.34, magnesium – 0.74, natrium and potassium – 1.60, hydrocarbons – 10.4, sulfates – 2.1, chlorides – 1.1. It is rather difficult to calculate the discharge of other elements because the discharge has a very irregular pattern and insufficient data collected in various water regime phases. Thus, only approximate estimates are possible at present to be specified with further studies.

Using the data provided by the Far Eastern Agency of Hydrometeorology and Environmental Monitoring, a quantitative analysis of phosphates and nitrite and nitrate nitrogen has been carried out. The data on average annual concentrations of these elements in the period from 1981 till 2003 were used. Mean content of nitrite nitrogen in Amur water in the multi-year period of observation is 0.016 mg/l. Based on annual average Amur run off 369.1 km^3, annual average discharge of nitrite nitrogen from the Amur into the sea is approximately 5 900 tons.

Nitrate nitrogen content in Amur water is estimated 0.110 mg/l based on annual average data on its content collected in 23 years of research. Annual average discharge of nitrate nitrogen from the Amur into the sea is approximately 41 000 tons.

Mean content of phosphates in Amur water in the multi-year period of observation is 0.050 mg/l. Annual average discharge of phosphates from the Amur into the sea is calculated as approximately 18 500 tons.

Based on perennial irregularities of the Amur run off, which maximal records exceed its minimal records 1.8 times, we can conclude that perennial biogenic matter discharge will also fluctuates within this range.

The reported data need further research and correlation to reveal dynamic regularities of Amur water quality in seasonal and perennial regimes.

Table 1. Trace metal content in water, μg/l, in September 2006 at Khabarovsk.

Element	Left bank, Surface	Left bank, Bottom	296 meters from the left bank, surface	296 meters from the left bank, bottom	571 meters from the left bank, surface	571 meters from the left bank, bottom	841 meters from the left bank, surface	841 meters from the left bank,	1021 meters from the left bank, surface	1021 м meters from the left bank, bottom	Right bank, surface	Right bank, bottom
Cr	2.37	2.37	0.67	1.93	1.08	1.02	0.68	0.86	2.01	1.02	0.87	0.90
Cu	4.72	4.22	5.32	1.38	72.75	2.20	7.32	3.07	2.31	15.28	4.00	4.05
Zn	0.35	1.14	18.18	–	56.67	–	23.98	–	–	85.63	1.68	0.03
Cd	0.02	0.05	0.06	0.01	0.09	0.01	0.10	0.01	0.09	0.71	0.10	0.06
Hg	–	–	–	–	–	–	–	0.17	0.10	–	–	–
Pb	0.88	0.87	1.08	0.78	2.34	0.82	1.72	0.79	0.85	2.73	2.04	1.32
Mn	43.40	47.55	39.09	48.43	35.90	56.82	53.14	55.98	49.41	61.65	71.37	75.77
Fe	957.58	1325.91	892.08	1112.54	796.96	1214.35	1055.45	1187.89	945.07	1773.15	1313.50	1393.03
Co	0.27	0.31	0.26	0.34	0.21	0.41	0.35	0.39	0.33	0.57	0.50	0.56
Ni	1.04	0.38	0.87	–	0.66	0.10	2.06	0.39	0.16	3.57	0.59	0.44
Sn	–	–	–	–	–	–	–	0.09	0.16	1.23	–	–
Sb	0.30	0.26	0.72	0.25	0.18	0.33	0.26	0.24	0.18	0.31	0.40	0.39

Table 2. Trace metal content in water, μg/l, in October 2006 at Komsomolsk-on-Amur

Element	Left bank, Surface	Left bank, Bottom	300 meters from the left bank, surface	300 meters from the left bank, bottom	500 meters from the left bank, surface	500 meters from the left bank, bottom	700 meters from the left bank, surface	700 meters from the left bank,	900 meters from the left bank, surface	900 meters from the left bank,	Right bank, surface	Right bank, bottom
Cr	0.70	1.44	0.92	0.75	0.77	0.82	1.00	0.95	0.83	1.79	1.86	0.97
Mn	55.23	90.49	72.95	65.45	62.02	67.49	64.72	61.24	46.02	61.45	67.43	43.01
Fe	1226.21	1938.20	1502.05	1589.54	1503.63	1628.12	991.87	958.09	796.83	1179.13	1108.53	865.65
Co	0.36	0.71	0.54	0.46	0.42	0.48	0.50	0.49	0.35	0.54	0.55	0.37
Ni	1.38	2.67	2.00	1.91	1.43	1.27	1.43	1.30	1.33	1.60	1.38	1.89
Cu	1.90	3.06	1.80	1.31	1.99	1.29	1.81	1.29	2.96	9.84	1.39	7.09
Zn	5.23	6.89	6.19	2.42	4.86	2.51	3.29	2.12	4.69	16.70	7.07	11.66
Cd	0.00	0.00	0.01	0.01	0.02	0.01	–	–	0.00	0.01	0.06	0.03
Sn	0.27	2.95	0.29	0.73	0.06	1.33	0.59	0.57	0.33	0.24	0.50	0.28
Sb	0.09	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.10
Hg	–	–	–	–	–	–	–	–	–	–	0.10	–
Pb	0.70	1.19	0.96	0.84	0.89	0.91	0.81	0.85	0.68	2.48	1.21	1.23

Table 3. Trace metal content in water, μg/l in October at Bogorodskoe

Element	Left bank, Surface	Left bank, Bottom	300 meters from the left bank, surface	300 meters from the left bank, bottom	500 meters from the left bank, surface	500 meters from the left bank, bottom	700 meters from the left bank, surface	700 meters from the left bank, bottom	900 meters from the left bank, surface	900 meters from the left bank, bottom	Right bank, surface	Right bank, bottom
Cr	2.43	1.14	0.77	1.21	0.97	1.19	0.66	0.71	0.95	1.07	1.90	0.86
Mn	44.50	75.38	56.85	83.19	46.05	64.52	38.97	46.61	62.66	70.04	52.74	45.60
Fe	886.63	1323.52	992.16	1371.45	872.29	1192.53	780.77	879.19	1098.44	1200.11	1074.83	925.87
Co	0.29	0.56	0.37	0.58	0.30	0.46	0.26	0.32	0.45	0.52	0.39	0.33
Ni	1.46	1.64	1.29	1.61	1.39	1.65	1.37	0.98	1.34	1.09	2.37	1.31
Cu	2.31	4.23	2.62	3.12	3.28	29.90	31.35	1.96	2.08	2.27	5.20	1.38
Zn	4.32	8.31	8.96	6.45	7.32	30.77	22.19	3.03	3.28	1.92	6.98	1.12
Cd	–	0.01	–	0.00	0.00	–	0.00	0.01	0.00	–	0.00	0.01
Sn	0.52	0.04	0.48	0.13	1.14	0.14	–	–	–	–	2.30	0.27
Sb	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.31	0.38	0.35	0.08	0.43
Hg	–	–	–	–	–	–	–	–	–	–	–	–
Pb	0.60	0.90	0.63	1.08	0.64	1.60	1.35	0.65	0.90	0.91	0.83	0.62

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