Impact assessment of solid runoff on heavy metals migration during high floods on the Amur river

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Abstract. Inhomogeneity of the concentrations of chemical elements in the cross-section of the Amur River is considered as a function of the state of their soluble and suspended forms. Flooding of wetlands and urbanized areas contributes to the removal of pollutants into the river channel. The wide spread of fens on the left bank contributes to the concentration of organic matter along the left bank of the river. Terrigenous material mostly comes from the right bank, where agricultural fields are concentrated. The ratio of their concentrations is maintained by the duration of the flood. The mechanisms of redistribution of elements between their suspended and soluble forms have been studied. The mechanisms of sorption of chemical compounds on mineral and organic colloids are described. It was found that mineral colloids with a negative charge due to electrostatic attraction sorb electrically neutral compounds (hydroxoaquacomplexes \[\text{[Mn(OH)}_2\text{(OH)}_2\text{]}^\text{0}\], ammonia \[\text{[Cu(NH)}_3\text{]}^\text{4(OH)}_2\text{]}^\text{0}\]. The role of organic material in the redistribution of chemical compounds between soluble and suspended forms is shown. Organic colloids with molecular mass > 5.0 kDa precipitate complex cations – \[\text{[Fe(HSO)}_4\text{]}^\text{+}\], \[\text{[Fe(HSO)}_4\text{]}^\text{2+}\], \[\text{[Cu(HSO)}_4\text{]}^\text{+}\]. An organic substance with a molecular mass of <2.0 kDa has a greater complexing ability for \text{Fe}^{2+}, \text{Cu}^{2+}, \text{Zn}^{2+}, \text{Mn}^{2+} ions. They bind metals to organo-mineral complexes by chemical interaction and form mobile organo-mineral complexes and heteropolar salts.

Keywords: Amur River, heavy metals, flood, organic matter

1. Introduction

Floods are an environmental problem for many rivers in the world. They lead not only to significant destruction, but also to the pollution of surface waters. Dozens of major floods in 2010–2020 happened on the rivers of East Asia [1]. Annually, they accounted for about 30–40% of the total number of cases. Floods determine the intensity of channel processes and the volume of sediment runoff.

The erosion of banks and floodplains determines a wide range of pollutants in the channel, which makes it difficult to analyze the structure of chemical compounds and does not allow an unambiguous description of the mechanisms of interaction in a multicomponent system of natural waters [2]. So far, the risks of pollution and the ecological safety of water resources remain a problem.

Studies of recent decades indicate that the rivers of Asia have entered a period of high water, which increases strategic risks for Russia and China. Floods on the Amur (2013, 2019, 2020) and the Yangtze (2012, 2018) were catastrophic. The Amur flood in 2013 was the largest over the past 120 years in the Amur region [1, 3]. It covered vast territories within Russia and China. The negative consequences of
this natural phenomenon associated with the transfer of terrigenous material and chemical pollution of the transboundary territory are of interstate importance. However, the current level of knowledge in the field of hydrochemistry is very limited, and insufficient knowledge of the mechanisms of their chemical interaction makes it difficult to correctly interpret the available results. The floods on the Amur, as the most studied, were used in this work to assess the mechanisms of pollution of river systems. The aim of this work is to assess the impact of floods on sediment runoff and pollution of the Amur, as well as to identify the role of organic matter in the mechanisms of migration of heavy metals and their compound coming from urbanized areas.

2. Subject and methods of research
The studies were carried out in the lower reaches of the Amur River on the segment between Khabarovsk and Komsomolsk-on-Amur cities during high summer-autumn floods. The content of heavy metals in dissolved and suspended forms was studied in the cross section of the river during the floods of 2013 and 2020. Water samples were taken near Khabarovsk and Komsomolsk-on-Amur cities from near-surface horizons above cities (7–10 km) and below (5–7 km) in the main channel of the river and uniformly across the entire width.

All samples of water and organic material were analyzed at the accredited analytical center for collective use by the Institute of Tectonics and Geophysics of the FEB RAS. To isolate the suspended phase, water samples were filtered (under vacuum) using nuclear filters with a pore size of 0.45 μm. The filtrates were poured into 50 ml containers and acidified with HNO₃ to pH = 2. The dissolved forms of metals were identified in the filtrates. The analysis method included inductively coupled plasma mass spectrophotometry (ICP MS) (Elan DRC II PerkinElmer instrument). The study area is shown in Figure 1.

3. Results and discussion
The main runoff of sediments and pollutants from the land surface to the Pacific Ocean is carried out from the territory of East Asia. The largest river systems, from the territory of which a large amount of terrigenous material and dissolved pollutants are carried out, are the Amur, Yangtze and Mekong river basins. The Amur has similar hydrological characteristics in many respects and therefore is an example for assessing the role of natural and anthropogenic factors in the transport of chemicals by large rivers.

3.1. Water regime and sediment runoff of the Amur River
The Amur River is characterized by a pronounced long-term variability of water and sediment runoff. Three causes of flooding on the Amur River have been identified:

1. Prolonged downpours in the basins of the Amur and its tributaries;
2. A small number of reservoirs and their insufficient volume to regulate the water flow in the Amur;
3. High floods on large tributaries, which are the Zeya, the Sungari and the Ussuri. The imposition of these conditions at the same time contributes to the development of a catastrophic flood below the Sungari mouth with water rise levels in the channel of -700–800 cm (at the Khabarovsk hydrological station). The record of water level rising up to 808 cm happened in 2013 (Figure 2, 3).

The Amur River has a pronounced long-term variability of water and sediment runoff [4]. The main part of the runoff of suspended particles of terrigenous material is made up of silty, organic and organo-mineral fractions (0.001–0.05 mm).

A significant amount of terrigenous material enters the river due to erosion of banks and polders. Flooding of bogs and the washout of fine fractions of organic matter into the channel creates heterogeneity of the suspended material and increases its mass. The average daily mass of suspended matter transferred during floods in the area between the cities of Khabarovsk and Komsomolsk-on-Amur is about 5.1 Mt. During the flood rise phase, the turbidity of the water in the river increases 2.5–3.5 times (Table 1). The turbidity of the water, due to the natural features of the catchment area of the river, is about 0.4 g/dm$^3$. The highest turbidity values are observed locally. The turbidity characteristics in the Khabarovsk-Komsomolsk-on-Amur section have been calculated and are shown in Figure 4 and Table 1.

The transport of a large mass of suspended material in the river channel is supported by high flow velocities and turbulence. The mass transfer of solid matter ($G$) through the cross-section of the river channel flow per unit time has the following expression [5]:

$$G = m_wVL + m_pV[dS/dt(1 - C_f)C/I]BdH/dL,$$

where $G$ is solid drain in the cross-section of the flow, passing per unit of time, kg/s; $m_w$ is the mass of the water volume enclosed between two calculated sections, kg; $I$ is a bed slope; $H$ is a flow depth, m; $L$ is the distance between calculated sections, m; $V$ is the flow speed, m/s; $t$ is time, sec; $m_p$ is the mass of suspended particles, kg; $f$ is the bottom layer friction coefficient; $C$ – is the sedimentation rate in water flow, kg/m·sec$^2$; $S$ is the flooded area, m$^2$; $B$ is the considered flow width, m.
The equation was used to calculate the total mass of suspended matter carried by the Amur stream during the 2013 flood (Table 2).

Table 2. Characteristics of high floods in the Amur River channel, 2013

| No | Flow parameters in the channel (straightened channel, (km)) | Parameters of the structure of terrigenous runoff in the river | Terrigenous runoff, the flood period, Mt | Gf/∑Gs Low water/Flood, % |
|----|--------------------------------------------------------|-------------------------------------------------------------|----------------------------------------|--------------------------|
|    | V(m/s): min/max Low water/Flood | L₁ | G₋ – OM (0.001–0.2₂₉ₙ) | Gf, Mt/s | Flood time, days | ∑Gsₙ | Gf | Low water/Flood, % |
| 1  | 2.0/2.25 Low water/Flood | 0.9 | 2.1/6.9 | 48.0/88.9 | 2.3/14.4 | 47 | 24 | 0.21 | 0.04/0.10 |
| 2  | 3.65/4.53 Low water/Flood | 5 | 1.8/7.5 | 45.1/82.8 | 45.1/82.8 | 51 | 26 | 0.23 | 0.04/0.10 |
| 3  | 1.95/2.06 Low water/Flood | 0.7 | 1.9/6.3 | 46.0/90.4 | 45.3/89.2 | 26 | 26 | 0.23 | 0.04/0.10 |
| 4  | 3.62/4.57 Low water/Flood | 5 | 2.1/6.8 | 45.3/89.2 | 26 | 26 | 0.23 | 0.04/0.10 |

No. is number of the sampling location; G is sediment discharge, mt/sec; Gf is sediment runoff per flood; Gs – suspensions; OM stands for organic matter.

An analysis of the magnitude of terrigenous runoff (fractions 0.001–0.05 mm) in the channel sections near Khabarovsk and Komsomol-on-Amur showed that during the flood its mass was (24–26) Mt. In the composition of these fractions, the proportion of fine silt increased 1.7 times, and the proportion of organic matter in 3–4. The natural waters of the Amur basin are ferrous; therefore, their affinity for Fe plays an important role in the migration of many chemical elements [6]. The duration of the flood over 10 days activates these processes. In the total chemical runoff of the studied metals (their suspended and dissolved forms), the sorption activity of mineral and organic colloids (70–100 μm) is of great importance. Sorption mechanisms are different:

1. Sorption, as an electrostatic attraction of electrically neutral atoms and their compounds, occurs on the surface of mineral particles with a huge specific surface area (m²/g) and a high negative charge [6]. Most often, hydroxoaqua complexes [Mn(OH)₂(OH₂)₆], ammoniates [Cu(NH₃)₄(OH)₂] are sorbed here, where complexing ions (Mn²⁺, Cu²⁺) firmly hold the outer sphere due to lone electron pairs of ligands [7]. The composition of the complexing ions determines the degree of stability of the compounds [8].

2. Organic colloids with a molecular mass of <2.0 kDa (fulvic acids) have a greater complexing ability in relation to ions Fe³⁺, Cu²⁺, Zn²⁺, Mn²⁺, Pb²⁺, Cd²⁺, Co³⁺. They bind metal compounds into organo-mineral complexes by chemical interaction. Complexes of metals with organic ligands under high turbidity conditions are sorbed on the surface of mineral particles. In total, the degree of binding...
of metal ions is 65-100% of the content of their dissolved forms [9]. Soluble organo-mineral complexes are unstable; they enter into ion exchange reactions with competing compounds and undergo biodegradation. However, our knowledge of the stability of metal complexes with organic colloids of various molecular masses is very limited.

The average contents of chemical elements in dissolved and suspended forms in the investigated section of the channel near the city of Khabarovsk during floods showed in Table 3. The indicators of their concentrations in both dissolved and suspended forms vary significantly along the channel width. The distribution of their concentrations in the cross-section of the Amur River is associated with the phenomenon of turbulence and swampliness of the floodplain.

High concentrations of dissolved Fe$_d$ and Mn$_d$ were revealed. Their maximum values are noted along the right bank of the river (731.1 and 15.9 µg/dm$^3$). Increased concentrations of dissolved forms of other elements are observed (Zn$_d$ in 3.2 times; Cu$_d$ – 2.6 times; Ni$_d$ – 2.1 times). High element concentrations in dissolved form along the right bank are caused by storm runoff from urban areas and industrial facilities. The content of Fe$_d$, Mn$_d$, Cu$_d$ and Zn$_d$ is considerably higher than their maximal and average parameters for world’s rivers [10, 11].

The proportion of compounds of many elements in suspended form prevails over dissolved ones, which is due to the high turbidity of the river [14]. The suspended form includes particles larger than 0.45 microns. They are represented by iron-containing minerals and colloidal compounds of the iron group, sorbed on suspensions [12]. The composition of suspended particles is dominated by Fe and Mn hydroxides associated with the organic matter of the suspension and with adsorption on the surface of the particles. A waterlogged area with a high content of organic colloids and suspended matter is developed along the left bank (Figure 5). Organic colloids bind metal ions into organo-mineral complexes, and they are carried out into the channel by a planar washout. The elemental composition of suspended matter becomes significantly different when mire waters mix with a flood wave in the river channel. The highest concentrations of Fe, Mn, Ni, Zn and Cd are associated with this phenomenon.

**Table 3.** Content of elements in the Amur River in the Khabarovsk region during the flood

| Sampling location             | *N   | Fe  | Mn  | Cr  | Co  | Ni  | Cu  | Zn  | Cd  | Pb  |
|------------------------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Above Khabarovsk:            |      |     |     |     |     |     |     |     |     |     |
| Dissolved form, 2019-2021    |      |     |     |     |     |     |     |     |     |     |
| Left bank 400 m              | 17   | 499.1 | 8.9 | 0.68 | 0.09 | 1.78 | 2.20 | 13.48 | 0.012 | 0.28 |
| Middle of the river          | 13   | 521.6 | 9.7 | 0.70 | 0.10 | 1.19 | 5.19 | 21.55 | 0.010 | 0.42 |
| Right bank 400 m             | 21   | 731.1 | 15.9 | 1.02 | 0.21 | 1.97 | 4.72 | 14.03 | 0.053 | 1.08 |
| World rivers, maximum [10]   |      | 410.0 | 7–10 | 1.0 | – | 0.3–2.5 | 3–7 | 15–20 | 0.01 | 1–3  |
| World rivers, average [11]   | 66   | 34  | –   | –   | 0.8 | 1.48 | 0.6 | 0.08 | 0.08 |
| Above Khabarovsk:            |      |     |     |     |     |     |     |     |     |     |
| Suspension form, 2013 (average) |      |     |     |     |     |     |     |     |     |     |
| Left bank 400 m              | 9    | 906.1 | 12.05 | 12.3 | 0.65 | 55.2 | 2.9 | 31.7 | 40.3 | 10.3 |
| Right bank 400 m             | 15   | 1105 | 8.35 | 15.1 | 0.98 | 3.2 | 65.4 | 34.1 | 6.2 | 14.0 |
| Rivers of Far Eastern Russia [12] |      |     |     |     |     |     |     |     |     |     |
| 3.2–6%  0.2%                 | –    | –   | 27–49 | 26–72 | 61–225 | 0.2–2 | 11–96 |
| World rivers [13]            | 5.1%  | 0.1% | –   | –   | 61–76 | 74–98 | 240–343 | 1.1–3.2 | 55–89 |

*N is number of samples

The turbidity of the river along the right bank is associated with the erosion of bank protection flood dikes and polders (Figure 6). The high content of suspended matter (> 1,000 mg/dm$^3$) to a greater extent controls the concentrations of Fe, Cu, Zn (Table 3).
The ratio between the total sum of metal concentrations in suspended form and that in dissolved form ($\sum{Me_{s}}/\sum{Me_{d}}$) shows a two-threefold increase. It persists with slight variability downstream from Khabarovsk to Komsomolsk-on-Amur. Bottom sediments strongly affect the content of heavy metals in suspended form.

### 3.2. Heavy metals in bottom sediments

Bottom sediments of the Amur channel were investigated in Khabarovsk Territory. It was revealed that fine fractions (0.001–0.05 mm) accumulate in the bank part of the river, which makes up about 15% of the total mass of bottom sediments [14]. Average indicators of the chemical composition of the fractions are presented in Table 4.

#### Table 4. The average content of heavy metals, in the bottom sediments near Khabarovsk city

| Water sampling location in the Amur | Fe (%), μg/kg | Mn, μg/kg | Zn, μg/kg | Cu, μg/kg | Pb, μg/kg | Ni, μg/kg |
|------------------------------------|--------------|-----------|-----------|-----------|-----------|-----------|
| **Section-1 (oil refinery area)**  |              |           |           |           |           |           |
| Left bank                          | 3.02         | 510       | 120.0     | 24.0      | 10.0      | 20.0      |
| Right bank                         | 3.66         | 680       | 260.0     | 74.0      | 38.0      | 41.0      |
| Left bank, railway bridge          | 3.01         | 470       | 120.0     | 39.0      | 20.0      | 18.0      |
| Right bank, the Khokhlatskaya creek| 3.28         | 460       | 240.0     | 34.0      | 18.0      | 20.0      |
| **Section-2 (the Amurskaya creek)**|              |           |           |           |           |           |
| Left bank                          | 2.98         | 410       | 300.0     | 30.0      | 20.0      | 26.0      |
| Right bank                         | 3.19         | 490       | 320.0     | 27.0      | 12.0      | 40.0      |
| Right bank, shipyard               | 5.06         | 870       | 370.0     | 72.0      | 67.0      | 172.0     |
| Then Amurskaya creek, vessels anchorage | 5.79       | 985       | 880.0     | 30.0      | 26.0      | 110.0     |
| Sedimentary rocks [15]             | 4.65         | 670       | 80        | 57        | 20        | 95        |

The data obtained show that industrial enterprises are the main source of pollution of the bottom sediments of the Amur. High concentrations of Zn – 880.0; Ni – 172.0; Cu – 72.0 and Pb – 67.0 μg/kg were found in places where industrial effluents were discharged from the shipyard, where vessels unusable for operation, being sources of metals penetrating into the bottom sediments, were anchored in the creek.

During a period of high water content, turbulent flows carry out fine fractions of bottom sediments into the open channel of the Amur. High rates are noted for Zn (260 μg/kg) and Cu (74.0 μg/kg) also in the area of the oil refinery. Water contamination with oil contributes to the deposition of heavy metals.

Indicators of concentrations of Zn, Cu, Pb and Ni in bottom sediments along the city’s bank are higher, respectively, in 2.1; 3; 3.8 and 2.0 times relative to the opposite bank. The excess of these metals remains at a distance of 60 km below the city. Thus, bottom sediments are an integral part of terrigenous runoff and migration of heavy metals in suspended form.
The study of the variability of chemical runoff in different parts of the channel during floods gives an integral idea of the role of organic matter in the migration of various metal compounds and pollution of watercourses in the river basin [16].

3.3. The role of organic matter in the migration of metal compounds

The chemical elements in natural waters migrate in the form of complex compounds with organic matter of various chemical nature and molecular mass [17]. Soluble humic acids and their complexes with heavy metals have an abnormally high mobility among the abiotic components of aquatic ecosystems [18]. By binding metal ions into complex compounds, organic matter contributes to their being in a dissolved state, thereby increasing their migratory mobility. Fulvic acids make the maximum contribution to the formation of soluble organo-mineral complexes [19].

Flooding of fens by flood waters enriched with oxygen leads to the formation of hydrated forms of iron and ferruginous nodules (Fe$_2$O$_3$·nH$_2$O). The intensification of the activity of microorganisms grows, which increases the fractionation of organic matter. Chelate compounds (colloids) and soluble aggressive fractions of fulvic acids are formed. The removal of a large mass of organic material into the Amur channel contributes to: a) the dissolution of pollutants resulting from flood washout from urban areas (potassium salts, urea, phosphates); b) ion exchange with the formation of hydroxo-complexes [Fe(H$_2$O)$_n$(OH)$_m$]$^{2+}$, [Cu(H$_2$O)$_n$]$_2^{2+}$ or ammoniates [Cu(NH$_3$)$_n$]$_2$(OH)$_2$.

Pollutants washed out by flood waters from urbanized areas dissociate as electrolytes into complex ions and ions of the outer sphere (for example K$_3$[Fe(CN)$_6$]=3K$^+$+[Fe(CN)$_6$]$^{3-}$). Complex ions [Fe(CN)$_6$]$^{3-}$ form double complex salts with fulvic acids. Aggressive fractions of fulvic acids have the ability to form with heavy metals mobile organo-mineral complexes and heteropolar salts (b):

\[
a) R(OH)(COOH) + (n+m)M^+ \rightarrow [MROHCOOM] (OM)m(γ(COOM)n-x + xyH^+ \\
\delta) R(OH)(COOH) + (n+m)M^+ \rightarrow R(OM)m(COOM)n + (n+m)H^+
\]

However, the concentration of fulvic acids in water is incommensurably lower than organic colloids and depends on the intensity of the biotic component’s development.

The content of organic matter and ferruginous organo-mineral compounds in water affects the water color. In the channel of the Amur near Khabarovsk, high water color indices were found near the left bank, where the surface of the floodplain is covered by fens (Figure 4). During floods, the ratio between allochthonous and autochthonous organic matter in the water flow along the waterlogged floodplain increases by 3–4 times. Organic colloids by sorption or chemical interaction with iron compounds (Fe$_2$O$_3$·nH$_2$O) form simple or complex organo-mineral compounds [20, 21]. The high mixing speed of the turbulent flow of the Amur River constantly changes their distribution in the cross section of the flow. Sometimes indicators of the content of organic matter and ferruginous organo-mineral compounds are used as a marker of the concentration of organic matter in water.

In the migration of chemical compounds in suspended form, not only organic compounds, but also the transfer of heavy metals in the composition of bottom sediments is of significant importance. The total volume of bottom sediment runoff in the lower reaches of the Amur is estimated at about 5 million m$^3$ per year.

Floods deteriorate water quality and cause pollution of bottom sediments of the Amur River [22]. Sources of chemical pollution of the Amur in floods are chemical emergencies, industrial wastewater and runoff from wetlands. The consequences of the accident at a chemical plant in Jilin, China in 2005 confirm this. Complete mixing of nitrobenzene discharged in the Amur after the accident on the Sungari, happened only after 550 km [23]. The interaction of chemical elements of industrial wastewater with organic matter form compounds that are in water in dissolved, colloidal and suspended states. The intensive use of land resources (polders) in the Amur basin in Russia and China also contributes to river pollution (Figure 5).

During floods, the phase equilibria of suspended and soluble forms of chemical elements are violated. The mixing of oxygen-enriched water masses promotes the oxidation of Fe$^{2+}$ to metahydroxide (FeO(OH)$_2$) and its accumulation in bottom sediments. Dissolved elements are in ionic form, organo-
mineral complexes and in the form of hydroxones. Especially dangerous is a high Fe$^{2+}$ content in soluble form [24]. Soluble pollutants are the most dangerous for fish fauna and public health.

4. Conclusions
The distribution of heavy metals and mass transfer in the Amur channel are associated with the swampy floodplain and the influx of industrial and urban wastewater. During large floods, intense erosion of the banks significantly increases the mass transfer of pollutants in the channel. The indicators of water turbidity increase up to 400 mg/dm$^3$, which is 4.5 times higher than the indicators of summer low-water period. The volume of solid runoff during a flood period increases more than 100 times.

Wetlands are a zone of biogenic accumulation of iron, manganese and copper compounds. Peat deposit is characterized by the accumulation of acidic forms of Fe$^{+2}$, Mn$^{+2}$, Cu$^{(+1)+2}$, Zn$^{+2}$. Flooding of fens by flood waters enriched with oxygen leads to the formation of hydrated forms of iron and ferruginous nodules (Fe$_2$O$_3$·nH$_2$O). Intensification of the growth of microorganisms contributes to the fractionation of organic matter. Chelate compounds and aggressive fractions of fulvic acids are formed. Aggressive fractions of fulvic acids have the ability to form mobile organo-mineral complexes and/or heteropolar salts with heavy metals.

The flushing of a large mass of organic substances into the channel promotes an increase in the soluble forms of many chemical compounds. The hydrochemical background is disturbed locally and quickly leveled out along the channel width. Concentration of metals in suspended form increases up to 3 times compared to that in dissolved form ($\sum$Me$_s$/$\sum$Me$_d$).

It has been revealed that the mass of terrigenous material (fractions 0.001-0.05 mm) in the channel sections near Khabarovsk and Komsomolsk-on-Amur during the flood period reaches (5.0–5.2)×10$^7$ mt per day. In the composition of these fractions, the proportion of fine silt increases by a factor of 1.7, whereas the proportion of organic matter shows a two-threefold increase. It was found that mineral and organic colloids (less than 70–100 μm) play a major role in the migration of metal compounds.

Mineral particles with a negative charge due to electrostatic attraction adsorb electrically neutral compounds such as ammoniates [Cu(NH$_3$)$_4$](OH)$_2]^0$ and hydroxoqua complexes [Mn(OH)$_2$(OH$_2$)]$^0$.

Organic colloids with the molecular mass >5.0 kDa mostly precipitate complex cations ([FeHSO$_4$]$^{+}$, [FeHSO$_4$]$_2$$^{+}$, [CuHSO$_4$]$_3$$^{+}$). Organic colloids with the molecular mass of <2.0 kDa have a greater complexing ability to ions Fe$^{(2)+}$, Cu$^{+}$, Zn$^{+}$, Mn$^{+}$, Pb$^{+}$, Cd$^{+}$, Co$^{+}$. They bind metals to organo-mineral complexes by chemical interaction. Prolonged floods intensify these processes.

The natural condition for the active pollution of the river with heavy metals is the flooding of wetlands, which occupy a vast area in the left-bank part of the Amur basin.

Now this study is supported by the Russian Foundation for Basic Research (RFBR), project No. 19-55-80022/20 and the National Natural Science Foundation of China (NSFC), project No. 5 1961145106. The research was carried out with the financial support of the Russian Foundation for Basic Research (RFBR), CNPq and NSFC in the framework of the scientific project BRICS2019-243.

Acknowledgments
We thank I. V. Perminova, Doctor of Sciences (Chemistry) and Professor of Moscow State University, Faculty of Chemistry, for valuable advices in preparing this article.

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