Mineralization and salt composition of the waters of the Middle Amur

V P Shesterkin* and N M Shesterkina

Institute of Water and Ecology Problems Feb RAS, 65 Dikopolteva Street, Khabarovsk, 680000, Russia

*Corresponding author’s e-mail: shesterkin@ivep.as.khb.ru

Abstract. The spatial and temporal variability of water salinity and salt composition of the Amur River near Khabarovsk in 2017–2021 was considered. An uneven distribution of water salinity over the river width was established, the greatest differences were observed in the winter low-water period, the lowest in the period of spring floods and floods. The maximum value of salinity was noted in winter, in the period of open channel – after very strong floods.

1. Introduction
Mineralization and salt composition of natural waters are important geochemical characteristics of the territory, depending on the composition of soils and bedrock, climatic conditions, water flow, and economic activities in the watershed.

The first data on the mineralization of Amur waters near Khabarovsk were obtained from observations by the Far Eastern Hydrometeorological Service (FE HMS) in 1949 (in 1943 and 1944, sodium and potassium ions, sulfate ions were not determined), which show a wide amplitude of fluctuations in mineralization values (38.6–137.7 mg/l). The lowest values were observed during spring floods and the highest during winter low-water periods. The average annual value was 68.7 mg/l. Sulfate and chloride ions did not exceed 8.9 and 4.0 mg/l, respectively. Calcium ion (31.9%-eq) dominated among cations and hydrocarbonate ion (40.7%-eq) dominated among anions.

Monitoring of FE HMS in 1950–1970 showed a wider range of mineralization of Amur waters (28.3–161.1 mg/l) with the average value of 75.0 mg/l. Considerable amplitude of the concentration fluctuations was noted for chloride (0.4–5.8 mg/l) and sulfate (2.7–15.4 mg/l) ions. There was a gradual decrease in calcium ion (from 30.8 to 24.4%-eq) and hydrocarbonate ion (from 41.9 to 34.4%-eq) in the salt composition, indicating an increasing influence of anthropogenic factors.

The intensification of economic activity in the Chinese part of the Amur basin and the appearance of large hydroelectric power plants in the Russian part had a great impact on the water and, consequently, the ionic runoff. Observations of the FE HMS near Khabarovsk in 1985–2009 indicated large mineralization limits (25.4–263.0 mg/l). Calcium and magnesium contents ranged from 4.6 to 20.2 mg/l and from 0.1 to 12.6 mg/l, respectively. The concentration of chloride (0.8–15.9 mg/l) and sulfate (<2.0–50.0 mg/l) ions varied over a wider range [1].

Studies by IWEP FEB RAS during the winter low-water period of 1997–2014 indicated a decrease in the minimum and maximum mean annual salinity values due to the appearance of the Zeya and Bureya reservoirs in the Amur River basin to 68.2 and 147.0 mg/l, respectively. The maximum value (up to 185.5 mg/l) was recorded in December 1998 after the historical flood in the Sungari River basin.
The average value for the winter was 96.7 mg/l, a decrease of 1.3 times compared with 1950–1967. The uneven distribution of salinity along the width of the Amur near Khabarovsk was due to the influence of the main tributaries that make up its flow: the Usuri, the Sungari, the Zeya, and the Bureya. The mean value of salinity over the observation period was 95.8 at the right bank (350 m), 102.7 in the middle (500–700 m) and 82.2 mg/l near the left bank (900–1100 m) [3]. During the open-channel period, the highest salinity value was observed after flooding in the Sungari River basin (up to 149 mg/l) due to salt removal from flooded fields in China.

In 2013, during the historical flooding of the Amur River near Khabarovsk, at the maximum water level during the observation period (808 cm), its salinity varied from 50.2–113.9 mg/l, with an average value of 73.5 mg/l [4]. Among the ions, there was a significant predominance of calcium ion and hydrocarbonate ion (24.8 and 38.0%-eq, respectively).

The emergence of the Nizhne-Bureya hydropower plant, as well as the flooding that became more frequent in recent years, made it necessary to study the salinity and salt composition of the Amur River waters near Khabarovsk for the period 2017–2021.

2. Materials and methods

Monitoring on the Amur River near Khabarovsk was carried out at 5–6 points evenly distributed along the river width during the winter low-water period (January–March, December) and the open channel period (May–October) in 2017–2021. Water samples were taken from the surface and analyzed at the Institute for Collective Use at the Institute of Water and Ecology Problems of the Far East Branch of the Russian Academy of Sciences (IWEP FEB RAS) according to the methods adopted for hydrochemical studies.

3. Results of the study

The winter low water in the Amur River near Khabarovsk in 2017–2021 was characterized by both increased (2017, 2020 and 2021) and decreased (2018, 2019) water availability (Figure 1). The high values were mainly due to increased water flows of the Zeya and Bureya rivers downstream of the HPP in December–February totaling 1744–1868 m³/s (in 2018–2019 they varied from 1349 to 1488 m³/s). The maximum water flow was observed in 2021, when water levels did not drop below -20 cm during the freezing period (Figure 1).

The salinity of the Amur River near Khabarovsk during the winter low-water period of 2017–2021 varied from 49.0 to 142.6 mg/l. Near the left bank it was in the range 49.0–95.8 mg/l, in the middle of the river – 88.6–142.6 mg/l, near the right bank – 87.8–125.2 mg/l. The largest difference in values across the width of the river was observed in the high-water year 2017 (69.1 mg/l), and the lowest in low-water 2018 (24.6 mg/l) [5]. A gradual decrease in salinity was observed in the mid- and near-left bank during the freeze-up period due to the influence of the regulated Zeya and Bureya rivers, characterized by low salt content (<40 mg/l) [6]. Mean winter values varied from 82.7 to 113.0 mg/l, with a maximum recorded in the high-water year 2021.

The long-term average value was 99.4 mg/l. 1.5 times higher than in 1997–2014. This increase in salinity with the increased flow of the Zeya and Bureya Rivers could have been caused by increased salt removal from the China. This is evidenced by the higher Cl⁻ and SO₄²⁻ concentrations in the middle Amur River (7.8 and 16.1 mg/l, respectively) in December 2021 than in 1950–1970, their contribution to the salt composition of water reached 5.8 and 8.9%, respectively.

The spring floods are observed in the II–III decade of April. The maximum water level was observed in April 2021, slightly lower in April 2020. In other years its value did not exceed 136 cm (Figure 1).

In April, because of ice drift, surveys on the Amur River are usually not conducted. The exception was in 2020, when the destruction of a dam on a tributary of the Sungari River necessitated monitoring on the Amur River [7]. Research near the left bank of the Amurskaya channel, into which the waters of the Amur flow through the Kazakevichyov channel (now the Fuyuan channel), testified to elevated values of mineralization and concentrations of ions of anthropogenic genesis. Water salinity reached 102.6 mg/l, Na⁺, Cl⁻, and SO₄²⁻ ions 10.6, 7.4, and 16.2 mg/l, respectively. Their contribution to the salt
composition of Amur waters was also maximal, up to 16%, 7.5 and 12.5% respectively. Near the right bank of the Amur, formed by the Ussuri River waters, their content was lower: 45.5, 3.2 and 6.5 mg/l, respectively. Their concentrations were slightly higher in the left-bank part of the Amur River channel – 78.7, 5.0 and 8.9 mg/l, respectively.

Figure 1. The water level of the Amur River near Khabarovsk in January-November 2017–2021.

In late April – early May the water level of the Amur River decreases sharply, and significantly in 2019. The maximum water flow due to increased autumn water content of the rivers and activation of cyclonic activity was observed only in 2021 (Figure 1).

Mineralization of the Amur’s waters at this time due to the feeding by rain and snow melt water decreases and varies within the range of 37.8–100.5 mg/l, averaging 64.9 mg/l. The maximum values due to a small flood formed in the Sungari River basin were observed in the right-bank part of the river in May 2020 (Figure 2). This is evidenced by the higher content of Na⁺, Cl⁻ and SO₄²⁻ (6.5, 4.5 and 12.8 mg/l, respectively) in this part of the Amur compared to other parts as well as their increased contribution (up to 11.3, 4.8 and 10%, respectively) to the salt composition. Across the Amur’s width, the largest differences in salinity (up to 45.0 mg/l) were in the high-water years 2020–2021, the smallest (up to 24 mg/l) in the low-water years 2017–2019.

The summer low water is short-lived, usually occurring between 2–3 and 6–8 days, only from June 1-27, 2018 values were less than -5 cm (Figure 1). Low flows were observed in July 2017 (20 cm), in June 2018 (-118 cm) and August 2020 (64 cm). In high-water years (2019, 2021), there were no periods with low water availability.

During the lowest summer low-water period in 2018, water salinity ranged from 50.1–76.0 mg/l, with an average of 64.2 mg/l. The difference in salinity values across the width of the Amur River between the right bank and the middle part reached 25.9 mg/l. Low content of nitrate nitrogen (<0.04 mg/l) was a peculiarity of water chemistry. In the middle of the river higher Na⁺ and Cl⁻ content was observed than in May (7.8 and 5.2 mg/l, respectively), contribution of these ions to salt composition was 13.5 and 6.5%.

Floods are specific to the natural conditions of the Amur basin, cover large areas, and have frequent recurrence. Very strong floods at water levels of more than 600 cm, i.e. a dangerous phenomenon (DP), were observed in 2019 and 2020 (Figure 1).

In 2019, a severe flood formed in July after the release of typhoon DANAS. Increased water content of the Amur River was promoted by the Bureya River, which had an average flow rate of 2383 m³/sec.
At the beginning of the flood the river caused the lowest annual water salinity in the middle of the river (up to 67.9 mg/l) and on the left Amur shore (41.4 mg/l) [8]. On the right bank the salinity increased due to the influence of the Sungari River (up to 72.4 mg/l). Average value was 53.4 mg/l. Na⁺, Cl⁻ and SO₄²⁻ content did not exceed 4.7, 3.5 and 9.4 mg/l (respectively).

Figure 2. Distribution of salinity in the water of the Amur River from the right bank to the left bank (m) near Khabarovsk in 2020

In August, exits of typhoons LEKIMA and KROSA along with water releases from the Bureyskoye reservoir, which averaged 3.28 m³/s, caused an increase in the water content of the Amur. At the peak of the flood, there were changes in the hydrochemical structure of the river caused by the increasing influence of the Sungari River, resulting in higher water salinity in the middle of the Amur than during the floods of 1998, 2002 and 2009 [3]. It reached 54.6 mg/l on the right bank and 48.5 mg/l on the left bank and averaged 61.3 mg/l. Comparison of the chemical composition of the Amur water at the flood peak in 2013 and 2019 indicated higher Na⁺ (up to 6.8 mg/l) and Cl⁻ (up to 4.7 mg/l) content in 2019.

Decrease of Amur level was prolonged due to release of typhoon LINGLING (Figure 1). Salt discharge from flooded fields in China caused the maximum salinity value during the open channel period, which varied from 75.7 to 115.3 mg/l, averaging 92.9 mg/l. The Na⁺ and SO₄²⁻ content at midstream reached 9.7 and 11.2 mg/l, was the maximum for the open channel period.

In the summer of 2020, the appearance of a very large flood on the Amur River was preceded by a small flood and deep summer low water (Figure 1). The flood was formed in late June mainly in the southern areas of Khabarovsk Krai and Jewish Autonomous Region. From 3 to 8 July the floodplain was under water. During the flood period water salinity varied from 44.8 to 89.2 mg/l, and averaged 67.1 mg/l. Amur waters at this time were characterized by higher Cl⁻ and SO₄²⁻ concentrations than in the 2013 and 2019 floods (7.1 and 12.4 mg/l, respectively).

Very strong flooding began to form in mid-August (Figure 1) as a result of active frontal divides, which caused high floods on the rivers of Primamurye. A great influence on the flow of the Amur, as well as in 2019, had the Bureya River, the water flow of which averaged 2455 m³/s (the maximum reached 5913 m³/s).
On the Amur River near Khabarovsk at the beginning of the flood at 450 cm water salinity in the middle and in the left bank of the river due to the influence of Russian tributaries, as in 2019, decreased, while on the right bank it remained unchanged. Therefore, there were no differences in salinity values between the left-bank and right-bank parts of the river, while in the middle due to the influence of the Sungari River was high. The Cl⁻ and SO₄²⁻ contents reached the lowest values (up to 3.3 and 7.4 mg/l, respectively) for the open channel period.

In September, former typhoon BAVI and then typhoons MAYSAK and HAISHEN caused flooding of the Amur floodplain to a depth of 3.3 m. Water discharges of the rivers Zeya and Bureya below the hydropower plant, unlike in 2019, did not have a big impact on the Amur's water content. At a water level of 540 cm water salinity across the entire width of the Amur, except in the middle, continued to decrease (Figure 2). Low levels of Na⁺, Cl⁻, and SO₄²⁻ (to 2.1, 1.4, and 4.0 mg/L) were observed in the left bank of the river, with SO₄²⁻ reaching 11.7 mg/l in the middle, was higher than in 2013 and 2019.

The decline of the Amur level was longer (Figure 1) than in the 2019 flood due to the western cyclone outfall in the Amur region. Water salinity due to salt removal from flooded PRC fields, reached maximum values in the middle of the river during the open channel period (up to 127.8 mg/l), on average was 96.4 mg/l. This value was higher in October and compared to the 2013 and 2019 floods. This salt runoff is indicative of increased economic activity in the Chinese part of the basin.

4. Conclusion.
Mineralization of Amur River water near Khabarovsk varies spatially and temporally over a wide range due to large differences in the chemical composition of its tributary waters. The maximum value of mineralization and concentrations of Na⁺, Cl⁻ and SO₄²⁻ due to the influence of the Sungari River are noted mainly in the middle of the Amur River in winter and at the fall of floods when large amounts of salts come from flooded fields in China.

Acknowledgments
The studies were carried out using the resources of the Center for Shared Use of Scientific Equipment "Center for Processing and Storage of Scientific Data of the Far Eastern Branch of the Russian Academy of Sciences", funded by the Russian Federation represented by the Ministry of Science and Higher Education of the Russian Federation under project No. 075-15-2021-663.

ORCID IDs
V P Shesterkin, https://orcid.org/0000-0002-7271-8228
N M Shesterkina, https://orcid.org/0000-0001-7053-6087

References
[1] Nikanorov A M, Spray V A 2011 Rivers of Russia Part IV. Rivers of the Far East (hydrochemistry and hydroecology) (Rostov-on-Don: NOC)
[2] Shesterkin V P, Shesterkina N M 2002 Maximum ionic drain of the Middle Amur Biogeochemical and geocological studies of terrestrial and freshwater ecosystems (Vladivostok: Dalnauka) pp 105–15
[3] Shesterkin V P, Shesterkina N M 2012 Spatial and Seasonal Variability of the Middle Amur Water Chemical Composition Water sector of Russia: problems, technologies, management 5 pp 18–28
[4] Shesterkin V P 2016 Variations of Amur water chemistry during the historical 2013 flood Water Resources 43(3) pp 495–503
[5] Shesterkina N M and Shesterkin VP 2019 Long-termdynamics of the ionic runoff in the Amur during winter low-water season at Khabarovsk and trends in its variations Water Resources 46(2) pp 258–65
[6] Shesterkin V P, Sirotskiy S E and Shesterkina N M 2014 Impact of Hydro Power Construction on the Solutes Content and Discharge in the Bureya River Water sector of Russia:
problems, technologies, management 4 pp 72–83

[7] Shesterkin V P 2021 The impact of the tailing pond dam destruction in the Sungari River basin (China) on the quality of the Amur River water near Khabarovsk in April 2020 *Geocology, engineering geology, hydrogeology, geocryology* 2 pp 67–74.

[8] Shesterkin V P 2020 Hydrochemical features of major floods in the vicinity of Khabarovsk in 2018–2019 *Meteorologiya i Gidrologiya* 11 pp 92–9