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HYDROCHEMISTRY, HYDROBIOLOGY: ENVIRONMENTAL ASPECTS

Ecological–Geochemical Conditions of Surface Water and Groundwater and Estimation of the Anthropogenic Effect in the Basin of the Ganjiang River

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Abstract—Data of studies of 2013–2019 were used to assess the current environmental-geochemical conditions of surface water and groundwater in the basin of the Ganjiang River, the largest tributary of Poyang Lake (China). The main objects of studies were the Ganjiang River, its tributaries—the rivers of Jinjiang and Yuanshui, groundwater of quaternary deposits in the valleys of the Ganjiang River and its tributaries, and the domestic and industrial wastewaters reaching the Jinjiang River. The analysis of the results included estimating the background concentrations of substances; the comparison of the chemistry of surface water and groundwater with the background characteristics and standards for domestic water quality accepted in Russia and China; the estimation of the saturation indices of river water, groundwater, and wastewater by some minerals and organomineral complexes; correlation and regression analyses aimed at revealing relationships between geochemical characteristics. In addition, the anthropogenic effect on the state of the Jinjiang River and groundwater in the Ganjiang River basin was evaluated by solving the diffusion equation and the transport equation, respectively. The conditions of water objects were found to be unsatisfactory because of the high concentrations of several toxic trace elements in individual river segments and groundwater; however, in general over many-year aspect, it satisfies drinking water quality standards introduced in China (by the total proportions between the actual and allowable concentrations). The state of the studied groundwater was poorer than that of surface water. This is due to the higher self-purification capacity of surface water in the region because of precipitation of poorly soluble compounds, coprecipitation of some trace elements on particles of river load and bottom sediments, and more intense water exchange.

Keywords: ecological–geochemical conditions, surface water, groundwater, water pollution, wastewaters, Poyang Lake basin, China

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INTRODUCTION

Poyang Lake is among the largest lakes in the world; it is located in the southeastern People's Republic of China (PRC). The lake is a part of the complex hydrographic network of the Yangtze River, with which it is connected by a channel; the lake practically regulates the flow of the Yangtze River and receives the waters of the Ganjiang, Xiushui, Fuhe, Xinjiang, and Raohe rivers. The drainage area of the lake is 162225 km^2 [19]; its water area averages ~4000 km^2, but it varies within a very wide range from 2.7–3 thous. km^2 to >5 thous. km^2 [24]. The resources and the conditions of surface water and groundwater in the Poyang Lake basin, the population of which is above 45.2 million (the average population density in the basin is about 270 per km^2, increasing to several thousand per km^2 [18]), is a key factor of the socioeconomic development of the region. At the same time, the lake and its catchment is the habitat of many animal species and the hibernating area of many bird species, including those included in the protection lists of the International Union for the Protection of Nature and the Red Book of Russia, as for example, white crane. All this determines the importance of studying the functioning of a complex natural–anthropogenic ecosystem of Poyang Lake; this ecosystem, in particular, is an object of studies of the experience of long-term interaction between the nature and community

(Nanchang, the largest town in the province, appeared in 201 BC).

The deterioration of the environmental–geochemical conditions of water bodies (the state of aquatic ecosystems, characterized by the chemistry of water and bottom sediments (BS), the regularities of their space and time changes, geochemical balance, and migration forms of chemical elements), both in the region under study and in China as a whole, is due to the discharge of large volumes of industrial, agricultural, and domestic wastewaters into them. According to data on the year of 2011, the annual volume of pollutants discharged into Poyang Lake was 2.52×10^7 t [31]. Until the early 1990s, >90% of industrial wastes in China was directly discharged into water bodies; almost 90% of towns had no centralized sewerage systems. Although the comfort in urbanized territories in China improves, the domestic sewage is often directly discharged into water bodies [15], and there are no centralized sewage systems in rural areas.

With this taken into account in Novembr 2019, a group of Russian, Chinese, and Indian researchers under BRICS STI Framework Programme, carried out a series of field and laboratory studies into the ecological–geochemical state of surface water, groundwater, and wastewater in the basin of Poyang Lake, which were a continuation of the earlier studies of groundwater. The objective of the study was to assess the current environmental–geochemical state of surface water and groundwater in the basin of the Ganjiang River, the largest tributary of Poyang Lake, which accounts for ~55% of water inflow into the lake [24].

MATERIALS AND METHODS

The main objects of the study were the Ganjiang River, its tributaries—the Jinjiang and Yuanshui, groundwater of quaternary deposits in the valleys of the Ganjiang and its tributaries, domestic and industrial wastewater entering into the Jinjiang River. The study objects and their locations were chosen such as to try to evaluate: (1) the general environmental–geochemical state of the surface water and groundwater in Ganjiang River basin and in the nearby areas; (2) variations in water chemistry along the Jinjiang River under the effect of wastewater; (3) variations in groundwater chemistry due to the pollution of its basin surface areas.

The source data, which can be conventionally divided into two parts, have been collected in the studies of 2013–2019. The first part of the data is a main body of data on groundwater chemistry, collected by a group of Russian and Chinese experts with the direct participation of E.A. Soldatova in 2013–2018 [27–30]. The second part, containing data on the chemistry of wastewaters, the water of the Jinjiang River, as well as the Ganjiang and Yuanshui rivers, and groundwater with a wider range of the examined chemical elements, was obtained in November 2019, when water levels in the Ganjiang River were minimal all over the observation period [22, 23].

In November 2019, water samples (Table 1; Fig. 1) were taken by researchers of the East China University of Technology (Nanchang) in cooperation with colleagues from the Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow; Tomsk Branch of the Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of Russian Academy of Sciences; and the National Institute of Technology Durgapur, India, taking into account the requirements of [17, 21]: surface water and groundwater in a well were taken from the top layer, 0.3–0.5 m from the surface; groundwater in the well was taken by a hand pump. Parallel to sampling, measurements were made to determine the electric conductivity EC, water temperature T_w, pH, and Eh, as well as the concentration of dissolved oxygen. The laboratory studies were carried out in a certified hydrogeochemical laboratory, Tomsk Polytechnic University (TPU) with the use of potentiometric (pH), titrimetric (Ca^{2+}, Mg^{2+}, HCO_3^-, CO_3^{2-}, CO_2, Cl^-, permanganate index (PI)), turbidimetric (SO_4^{2-}), photometric (NH_4^+, NO_2^-, NO_3^-) methods, ion chromatography (Na^+, K^+) with the use of ionic chromatographs ICS 1000 and ICS 2000 (Dionex, USA), mass-spectrometric method with inductively coupled plasma with the use of NexION 300D mass-spectrometer (PerkinElmer, USA) (other elements, including Si, Li, Al, P, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Ag, Cd, Sn, Sb, Cs, Ba, La, Ce, Sm, Eu, Tb, Yb, Lu, Au, Hg, Pb, Bi). Also, the total concentration of dissolved organic carbon DOC was determined with the use of high-temperature catalytic oxidation (analyzer TOC/TNb Vario TOC cube, Elementar, Germany). The procedure of groundwater sampling and analyses in 2013–2018 was in general similar to that mentioned above [25, 27].

The analysis of the results of field and laboratory studies included the following.

(1) Estimation of background concentrations (in this case, understood as a characteristic of the expectation under the existing natural–anthropogenic conditions) of substances C_b in river water as the upper limit of determination of the geometric mean values of C_g [3, 5]:

$$C_b = C_g \exp\left(\frac{3\sigma_{\ln C}}{\sqrt{N}}\right), \quad (1)$$

$\sigma \ln C$ is the root-mean-square deviation of logarithms of concentrations; N is sample size; C_g and C_b were calculated with the use of data of studies on Poyang Lake: 11 samples of river water taken in 2013 and 2019

Table 1. Study objects during the low-water season of 2019

No.	Object	Site	Sampling date
P104	Ganjiang R.	10 km upstream Nanchang	Nov. 4, 2019
P95	Jinjiang R.	0.5 km from the mouth, 23 km from Nanchang	Oct. 31, 2019
P102	Jinjiang R.	Downstream of Yunyan, 86 km from Nanchang	Nov. 1, 2019
P100	Release no. 1 of wastewater into the Jinjiang R.	0.09 km upstream P102, 86.09 km from Nanchang	Nov. 1, 2019
P101	Release no. 2 of wastewater into the Jinjiang R.	0.18 km upstream P102, 86.18 km from Nanchang	Nov. 1, 2019
P98	Jinjiang R.	159 km from Nanchang	Nov. 1, 2019
P99	Groundwater, well	Left bank, 0.15 km from P98 site	Nov. 1, 2019
P96	Yuanshui R.	116 km from the mouth (the mouth is within 87 km from Nanchang)	Nov. 1, 2019
P97	Groundwater, well	Left bank, 0.04 km from site P96	Nov. 1, 2019

(Fig. 1b); 26 samples of groundwater taken in 2013, 2017–2019 (Fig. 1b); all concentrations are in mg/dm^3.

(2) The comparison of the chemistry of surface water and groundwater with the background Z_C (2) and with water quality standards for domestic use $C_{\lim}$ (Russian [2] and Chinese [20] standards were used for comparison) by relationship (3):

$$Z_C = \sum \frac{C}{C_b} - (N_Z - 1), \qquad (2)$$

$$\sum_{1-2} \frac{C}{C_{\lim}} \le 1, \qquad (3)$$

N_Z is the number of substances, the concentrations of which are greater than their background values C_b by a factor >2 [3]; according to [13], water quality is classi-

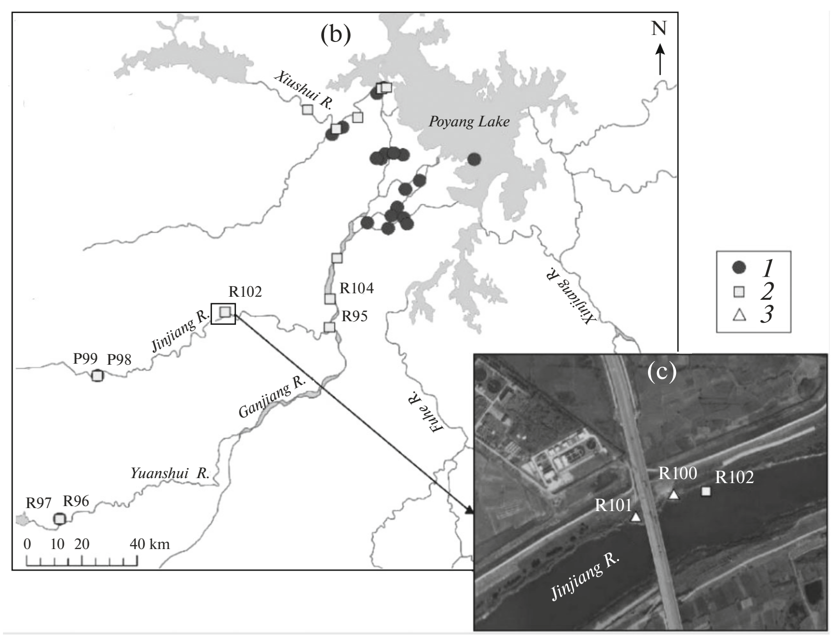

Fig. 1. Schematic map of sampling: (a) the study area in the map of China; (b) layout of the points of sampling (*1*) groundwater and (*2*) surface water involved in the calculation of background concentrations; (c) layout of wastewater discharge sites (*3*) near Jinjiang River. The numbered points were sampled during low-water season of 2019 (Table 1).

fied as unsatisfactory when the condition (3) is not satisfied for substances with hazard classes 1–2.

(3) The calculation of saturation indices SI for river water, groundwater, and wastewater with respect to mineral and organomineral complexes:

$$SI = \log PA - \log K_{\text{neq}}, \quad (4)$$

PA is the activity product of the group of substances; K_{neq} is the instability constant; the procedure of thermodynamic calculations is given in [12].

(4) Correlation and regression analysis; the coefficient of correlation r_{xy} of variables x and y (5) and the coefficient of regression in terms of module were assumed statistically significant (with significance level of 5%) if they were greater in terms of module than the double error of their determination; in the case of regression relationship, an additional condition is the square of the correlation ratio $R^2 > 0.36$:

$$|r_{xy}| \geq 2\frac{1 - r_{xy}^2}{\sqrt{N-2}}. \quad (5)$$

In addition, the anthropogenic effect on the state of the Jinjiang R. and groundwater in the Ganjiang R. drainage area was assessed with recommendations [8, 11, 16] taken into account. The propagation of matter in Jinjiang R. as the result of mixing and transformation of domestic and industrial wastewater was calculated by solving a diffusion equation under the following assumptions: (1) two-dimensional approximation can be used; (2) advective transport of matter along the flow dominates (coordinate x); (3) diffusion transport across the flow (coordinate y) dominates; (4) changes in the concentration C of the matter in water is proportional to its deviation from some equilibrium value C_{es},:

$$\vartheta\frac{\partial C}{\partial x} \sim D\frac{\partial^2 C}{\partial y^2} + k_{cs}(C_{es} - C), \quad (6)$$

ϑ is flow velocity, m/s; D is the coefficient of hydrodynamic dispersion, m^2/s; k_{cs} is the specific rate of change of concentration C, s^{-1}; the numerical solution of (6) was made by first-order explicit method using A.V. Karaushev procedure [8]:

$$\frac{q_w}{2h_a\vartheta_a} \leq \Delta y \leq 0.1B, \quad \Delta x = \frac{\vartheta_a \Delta y^2}{2D}, \quad (7)$$

$$C_{i+1,j} = \frac{C_{i,j+1} + C_{i,j-1}}{2} + \frac{\Delta x}{\vartheta_a}k_{cs}\left(C_{es} - \frac{C_{i,j+1} + C_{i,j} + C_{i,j-1}}{3}\right), \quad (8)$$

where h_a and B are the mean flow depth and width, m; ϑ_a is the mean flow velocity, m/s; q_w is wastewater discharge (or inflow water discharge); i is the step with a length of Δx along the flow along x axis; j is the step with a length of Δy across the flow along y axis.

The characteristics of the flow and the discharges of wastewater were calculated by hydraulic method using field data as of November 1, 2019, taking into account [14]: the discharge of industrial wastes P101: $q_{w\text{P101}}$ = 0.012 m^3/s; the discharge of domestic wastes P100: $q_{w\ \text{P100}}$ = 0.137 m^3/s, h_a = 0.57 m, B = 150 m, ϑ_a = 0.57 m/s, D = 0.0082 m^2/s, Δx = 9.00 m, Δy = 0.51 m.

The values of C_{es} were taken equal to the geometric means and the values of C_b, by equation (1). The parameter k_{cs} was chosen by the condition:

$$\frac{100 \times |\Phi_s - \Phi_o|}{\Phi_o} \to \min, \quad (9)$$

where Φ_o and Φ_s are the observed and calculated values of the examined variable. The analysis of model (8) showed that it is reasonable (under the condition of minimum of (9)) to use geometric mean values to approximate C_{es}.

Groundwater pollution in the top aquifer (shallow groundwater) was evaluated with the use of an analytic solution of a one-dimensional transport equation (analogous to (6) but with the field groundwater velocity u) with the assumption that water of anthropogenic origin with elevated concentration C_w is present on the catchment area:

$$C = C_{es} + (C_w - C_{es})\exp(f(u,k)z), \quad (10)$$

where z is depth, $f(u, k)$ is a function of u and the specific rate of matter transformation. As well as in (8), C_{es} in (10) were taken equal to the geometric means and the values C_b (1), but calculated by data on groundwater. The choice of $f(u, k)$ for all samples and C_w for each sample was made by the condition (11):

$$\frac{S}{\sigma} = \sqrt{\frac{\sum(\Phi_{s,k} - \Phi_{o,k})^2}{ND_\Phi}} \leq 0.8, \quad (11)$$

where Φ_o and Φ_s are observed and calculated values of the examined variable; D_Φ is the variance of the observed value of Φ_o; N is the number of samples. The agreement for either river water or groundwater was the best when geometric mean values were used ($C_{es} = C_g$).

RESUULTS AND DISCUSSION

According to classifications [1, 4, 6], the surface waters under consideration are fresh with low TDS values, hydrocarbonate calcium of the first and second types; neutral, from oligosaprobic, pure (the rivers of Ganjiang and Yuanshui) to mesosaprobic, polluted (Jinjiang River). The groundwater in the Ganjiang River basin, as it has been shown before in [25, 30], is fresh with low and medium salinity, hydrocarbonate calcium, of the second and third types; slightly acidic and neutral; by their mean values, they are mesosaprobic, polluted; they do not satisfy the condition (3) by

Russian domestic–drinking standards, but are close to drinking water standards used in the People's Republic of China (Table 2). It should be mentioned that the arithmetic means of the sum $\sum_{1-2}\frac{C}{C_{\text{lim}}} < 1$ for river water and groundwater over the entire observation period is <1 according to either Russian or Chinese standards, and these values are greater for groundwater than for river water (the value of $\sum_{1-2}\frac{C}{C_{\text{lim}}}$ for river water: Russian Federation (RF) standard is 0.45, People's Republic of China (PRC) standard is 0.13; the value of $\sum_{1-2}\frac{C}{C_{\text{lim}}}$ for groundwater: RF standard is 0.90, PRC standard is 0.42). Wastewater from one of the examined discharge sites is fresh with low TDS values, hydrocarbonate calcium, neutral, hypersaprobic, polluted; water from other discharge site is fresh with high TDS values, sulfate sodium, weakly alkaline, polysaprobic, polluted (Table 2).

The concentrations of substances in the studied river water are generally comparable and lie within the limits of the determination error of mean values at significance level <5%. The values of Z_C calculated by formula (2) for groundwater are higher than the values of C_b, calculated by (1). The values of Z_C for wastewater are even greater, especially, in the industrial wastes at point P101 (Table 2). The same site shows the maximal violation of condition (3), which somewhat differs from water quality estimate by [4]. This is due to the fact that the requirements [4] are largely aimed at the estimation of nutrient concentrations, and the concentration of nitrate ion is recorded at the level of 44 mg/dm^3 at point P100 and at 2.35 mg/dm^3 at point P101. Here, we do not take into account the excess relative to some standard values for the actual concentrations of trace elements, peaks of which were detected exactly at point P101. The very high concentrations of W (3.061 mg/dm^3), Hg (0.071), Mo (0.250), Br (0.280), As (0.089) and some other elements should be also mentioned.

However, as near as 90 m downstream from wastewater discharge site P101 (point P102), their concentrations abruptly drop (Table 2). To explain this fact, propagation of substances in the flow was calculated by equation (8). It was found that, first, the use of the equation allows one to obtain sufficiently good agreement between the measured and calculated values of hydrochemical characteristics at point P102; second, the concentrations of the substances entering the Jinjiang River through discharges P101 and P100 decreased considerably within 200 m from the discharge even during the very low dry season of 2019 (Fig. 2); third, even for the substances considered inert, not only dilution of wastewater by river water, but also the processes of self-purification (in particular, the precipitation of poorly soluble compounds and sorption on particles of river load and bottom sediments) are important factors contributing to concentration decrease.

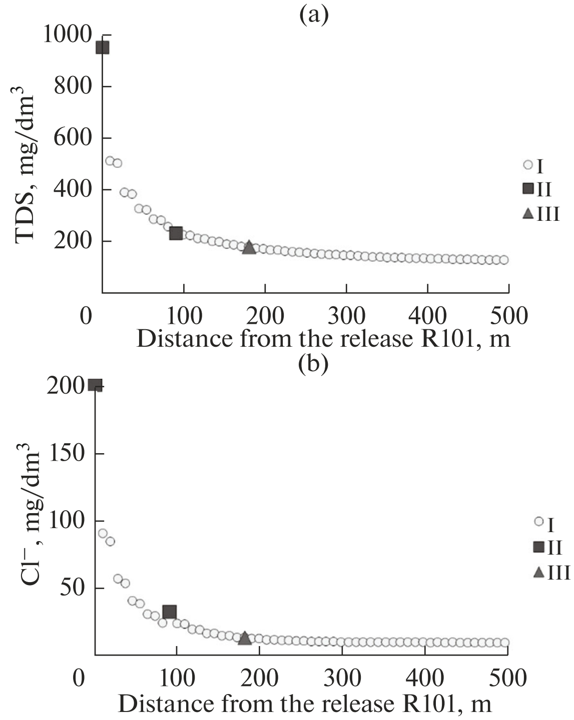

Fig. 2. Calculated (in the maximally polluted stream) and measured of (a) the total dissolved solids NO_3^- (TDS) and (b) Cl^- concentrations in the Jinjiang River: (I) calculation by equation (8); concentrations measured (II) in wastewaters of the discharges R101 and R100; (III) in Jinjiang River, point R102 (Table 1, 2).

To verify this assumption, thermodynamic calculations were carried out and showed that all studied waters, sampled in November 2019, can solve feldspars, but are close to equilibrium or oversaturated with respect to quartz, clay minerals, and (tentatively) calcium and magnesium compounds with humic acids (HA). In the latter case, the calculation was made assuming a linear relationship existing between PI and HA concentrations (HA = 0.085 PI; $R^2 = 0.47$; the size of the sample on rivers and groundwater of Siberia is 103). It should be mentioned also that wastewater at point R101 and groundwater at point R97 are somewhat oversaturated with respect to calcite, dolomite, and muscovite. At other points, the examined water was undersaturated with respect to these minerals. In addition, wastewater at point R101 lied in the domain of stability with respect to montmorillonite, while other water, to kaolinite.

In addition to thermodynamics calculations, correlation and regression analyses were carried out. Despite the small number of samples, their results are in good agreement with both the theoretical conclusions regarding the equilibrium–nonequilibrium

Table 2. The chemistry of surface water, groundwater, and wastewater in 2019 and on the average over 2013–2019 (C_g and C_b are the geometric means and the upper limit of their determination by formula (1); Z_C and $\sum_{1-2} \frac{C}{C_{\lim}}$ were calculated by (2, 3))

Characteristic	Nos. of sampling points in 2019 (Table 1)									River water, 2013–2019		Groundwater, 2013–2019	
	P104	P95	P102	P100	P101	P98	P99	P96	P97	G_g	G_b	G_g	G_b
pH	6.95	6.98	6.99	6.93	7.55	6.96	6.22	7.25	7.10	7.00	7.26	6.39	6.61
	mg/dm^3												
CO_2	3.5	7.0	3.5	7.0	3.5	3.5	18.5	3.5	5.3	5.9	13.7	29.4	48.8
PI	1.30	2.48	1.14	2.22	2.80	1.30	0.08	1.92	0.27	1.42	2.05	0.97	4.01
DOC	0.50	1.17	1.27	2.29	6.80	1.04	0.50	1.45	0.50	2.73	17.21	0.93	1.41
TDS	117.9	180.8	180.3	234.1	951.7	176.8	178.1	180.5	431.4	120.7	173.2	178.6	244.8
Ca^{2+}	16.9	26.1	27.6	28.2	89.1	24.4	14.0	29.3	63.9	17.4	24.8	18.5	27.7
Mg^{2+}	4.0	3.6	3.4	3.8	9.2	3.2	4.6	3.9	16.3	3.1	4.1	5.6	8.0
Na^+	8.4	14.9	14.3	24.1	175.8	19.8	9.7	7.9	11.7	9.0	13.8	13.2	18.7
K^+	2.3	2.8	2.9	9.0	23.2	2.5	28.8	2.3	16.1	2.1	2.8	3.9	8.2
HCO_3^-	59.0	92.0	93.0	69.0	132.0	87.0	34.0	110.0	231.0	59.8	92.7	72.8	107.2
Cl^-	13.5	15.4	14.0	33.0	200.0	10.8	10.0	8.6	45.0	10.4	15.8	13.4	26.0
SO_4^{2-}	13.6	25.8	25.0	23.0	320.0	29.0	42.0	18.4	25.9	11.9	30.6	9.8	23.5
NO_3^-	0.05	0.05	0.05	44.00	2.35	0.05	35.00	0.05	21.60	0.37	2.50	5.01	18.02
NO_2^-	0.01	0.01	0.01	0.01	0.01	0.01	0.11	0.01	0.01	0.01	0.02	0.03	0.06
NH_4^+	0.03	0.08	0.03	0.063	0.47	0.03	0.03	0.03	0.03	0.13	0.54	0.20	0.73
P	<0.02	0.05	0.05	0.51	0.15	0.03	<0.02	<0.02	0.06	0.02	0.04	0.02	0.04
Si	5.75	4.81	5.69	4.63	3.55	5.11	3.00	3.91	8.18	5.43	7.89	8.29	11.62
Fe	0.224	0.131	0.039	0.043	0.175	0.062	0.016	0.025	0.096	0.275	1.818	0.308	1.720

Table 2. (Contd.)

Characteristic	Nos. of sampling points in 2019 (Table 1)									River water, 2013–2019		Groundwater, 2013–2019	
	P104	P95	P102	P100	P101	P98	P99	P96	P97	G_g	G_b	G_g	G_b
	μg/dm^3												
Li	13.65	20.22	48.95	9.07	88.62	39.77	0.45	33.86	1.07	28.31	57.09	0.50	1.75
Al	34.06	37.95	11.32	7.06	167.09	16.35	7.14	5.09	3.63	16.48	50.09	4.70	8.86
V	0.63	1.40	1.34	0.84	80.20	1.05	0.13	1.42	3.13	1.12	1.78	0.16	23.54
Cu	1.18	1.12	0.71	0.43	4.12	0.95	0.51	0.48	0.91	1.25	2.40	1.26	3.47
Zn	0.68	0.43	0.49	3.87	14.23	0.87	3.96	0.05	13.57	1.68	8.90	5.39	11.50
As	1.73	2.21	1.82	1.69	89.40	1.66	0.10	2.08	0.77	1.89	2.23	0.13	2.48
Mo	1.03	0.67	1.17	0.46	250.24	0.26	0.01	1.48	0.73	0.79	1.98	0.13	6.61
Cd	0.037	0.022	0.001	0.003	0.176	0.019	0.071	0.004	0.042	0.003	0.010	0.003	0.013
Sb	0.18	0.28	0.39	0.28	32.56	0.22	0.05	0.18	0.20	0.24	0.37	0.07	0.37
W	0.35	1.05	11.44	0.07	3060.60	0.15	0.02	0.13	0.05	0.60	7.18	0.03	0.06
Pb	0.74	0.56	0.09	0.07	0.38	0.25	1.35	0.04	0.51	0.30	1.72	0.75	2.06
La	0.892	0.444	0.053	0.010	0.131	0.094	0.963	0.026	0.137	0.139	1.002	0.308	1.791
Ce	1.941	1.106	0.119	0.020	0.179	0.225	0.033	0.051	0.025	0.311	2.402	0.060	0.536
U	0.258	0.509	0.378	0.006	1.172	0.352	0.004	0.887	1.023	0.434	0.812	0.052	6.209
	Characteristics of water pollution in relative units												
Z_C	3.6	2.1	1.0	63.7*	903.2*	1.0	8.2**	1.0	6.8**	–	–	–	–
RF: $\sum_{1-2}\frac{C}{C_{\lim}}$	1.5	2.6	3.2	1.3	226.1	3.9	1.6	1.8	1.5	2.7 (0.45)***	6.6	2.3 (0.90)***	6.6
PRC: $\sum_{(1-2)}\frac{C}{C_{\lim}}$	0.7	0.8	0.7	0.6	91.6	0.7	1.5	0.5	0.8	0.8 (0.13)***	6.6	2.3 (0.42)***	6.6

* Z_C in wastewater was evaluated with the use of background concentrations for river water (11 samples).

** In groundwater: background concentrations for groundwater (26 samples).

*** Given in parentheses are the arithmetic mean of the ratio over all samples, given without parentheses is the ratio of C_g or C_b to the standard; $\sum_{1-2}\frac{C}{C_{\lim}}$ was calculated based on Russian Federation (RF) standards for the following substances: Na, NO_2^-, Li, Co, Ni, As, Se, Br, Sr, Nb, Mo, Ag, Cd, Sb, Te, I, Ba, W, Hg, Tl, Pb, Bi, U; People's Republic of China (PRC) quality standards do not specify hazard classes, and the calculations were made for substances Na, NO_2^-, Ni, As, Se, Mo, Ag, Cd, Sb, Ba, Hg, Tl, Pb; PI (permanganate index and DOC (the total concentration of dissolved organic carbon); TDS the sum of ions Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^-, NO_3^-; the concentrations of CO_3^{2-} in all samples is below detection limit (<3 mg/dm^3).

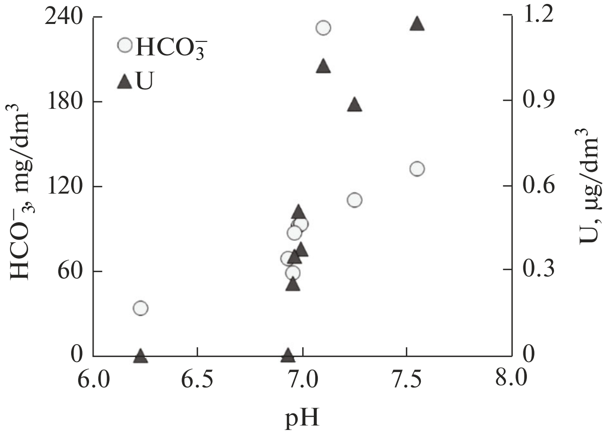

Fig. 3. Dependence between pH and the concentrations of HCO_3^- and U in surface water, groundwater, and wastewater in the drainage basin of the Ganjiang River during the dry season of 2019.

character of the evolution of water–rock system [26] and the results of earlier studies of groundwater in the Poyang Lake drainage basin [25]. In particular, feedbacks were found to exist between pH, on the one hand, and the concentrations of CO_2 and trace elements Y, Tl, Pb, La, Pr, Nd, Sm, Eu, Gd, Tb, Dy, and Er (from $r = -0.85 \pm 0.11$ for CO_2 and Tl to $r = -0.56 \pm 0.26$ for Er), which indirectly indicates to the precipitation of poorly soluble hydroxides of some metals and coprecipitation of some other substances, including rare-earth elements. Accordingly, direct correlation between pH and hydrocarbonates ($r = 0.56 \pm 0.26$) was found to exist (Fig. 3). The latter contribute to the formation of hydrocarbonate and carbonate complexes and the accumulation of some elements in solution, for example, U (for pH and U concentrations, $r = 0.80 \pm 0.14$) in the form of uranyl-carbonate complex [9, 10].

Similar conclusions were obtained for shallow groundwater as a result of model test (10), which showed that (assuming the surface source of pollution above background concentrations, calculated by equation (1)) their pollution is most likely due to applying fertilizers and livestock supplement at agricultural objects with transformation of organic matter (of both fertilizers and plant and animal residues), as well as the input of substances with domestic wastewaters from settlements (Table 3). The data obtained suggests an assumption that the state of shallow groundwater will improve after a decrease of the load from diffuse sources, the problem of management of which is discussed in detail in [7].

CONCLUSIONS

The surface water and groundwater in the basin of the Ganjiang River suffers considerable and long-term anthropogenic load, because of which their state is estimated as unsatisfactory because of the high concentrations of several toxic trace elements in individual river sigments and in groundwater; however, on the long-term scale, this state generally meets the standards of drinking water quality established in PRC. The state of groundwater in the Ganjiang basin is somewhat worse than that of surface water because of the higher self-purification capacity of surface water in the study area due to the precipitation of poorly soluble compounds and co-precipitation of some trace elements on particles of river load and bottom sedi-

Table 3. Calculated concentrations of substances C_w in water of anthropogenic origin, which are supposed to enter the aquifer from drainage basin surface (given in parentheses are the values $C_w < C_b$)

No.	Groundwater sampling point	Date	Depth z, m	Cl^-	NO_3^-	NH_4^+
				mg/dm³		
P99	Well in Jinjiang R. Valley, Quaternary deposits	Nov. 1, 2019	5.2	(0.0)	46.08	(0.00)
P97	Well in Yuanshui R. Valley, Quaternary deposits	Nov. 1, 2019	7.7	65.3	31.53	(0.00)
P93	Well (abandoned) in Poyang Lake coastal zone	Oct. 29, 2019	8.4	30.0	23.17	3.66
P91	Well in Ganjiang drainage basin. Settlement Feng Zhou	May 16, 2018	10.8	(0.0)	(0.00)	6.64
P90	Well in Ganjiang drainage basin. Shang Hekou Settlement	May 16, 2018	18.0	(0.0)	(0.00)	19.65
P83	Well in Ganjiang drainage basin in the floodplain of the Tiehe R., Xiangshen Settlement	May 16, 2018	12.1	58.5	101.09	(0.00)
P83	The same	Nov. 12, 2017	12.1	126.3	156.52	(0.00)
P12	Well in the Ganjiang drainage basin, Xiangshan Settl.	Oct. 19, 2013	16.0	54.1	115.70	5.19
P11	Well in the Ganjiang R. basin, Wali Settl.	Oct. 19, 2013	10.0	80.6	76.67	(0.00)
P8	Well in the coastal zone of Poyang Lake at the inflow of the Ganjiang River into the lake	Oct. 19, 2013	10.0	49.0	41.56	(0.00)

ments. An important factor of self-purification appears to be biogeochemical processes in water at its temperature >20°C (in October–November 2019, river water temperature varied from 21.1 to 22.8°C; that of shallow groundwater, from 21.5 to 22.5°C; and that of wastewater, from 22.0, 23.3°C).

The rate of water exchange can be seen to have an effect on the ecological–geochemical state of the studied water. This parameter determines the general conditions of interaction in the water–rock system (contact time and area, export of reaction products) and indirectly regulates the rate and direction of biogeochemical processes, which, in turn, regulate the concentration of dissolved CO_2, for example, through its consumption in photosynthesis (this assumption is indirectly confirmed by the relatively low PI values). In this way, it has a considerable effect on the carbonate system and, accordingly, on the self-purification of surface water and groundwater through removal of poorly soluble substances (supposedly, clay minerals and hydroxides of some metals) and co-precipitation of some trace elements. Under the effect of both these factors, an appreciable decrease in the concentrations in Jinjiang River water can be seen as near as ~200 m from wastewater discharge site, and the best water quality is typical of Ganjiang, the river with maximal water flow.

Despite the considerable self-purification capacity of both surface water and groundwater, we have to mention the need for the further improvement of wastewater treatment, and the stricter control of anthropogenic activity in the coastal zone of Poyang Lake and its tributaries, as well as in the catchment areas with poorly protected aquifers (in the absence of aquicludes and at large enough values of soil hydraulic conductivity).

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