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Characteristic features of groundwater pollution in the Poyang Lake catchment

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Abstract. Research of shallow groundwater in the Poyang Lake catchment should be considered as one of the priority targets in this region, due to the fact that shallow groundwater is formed under the influence of complex factors, including both natural and anthropogenic, and also the fact that it is related to the Poyang Lake water. Shallow groundwater of the Poyang Lake area is fresh. High concentrations of NO_3 ,Cl^-, SO_4^{2-}, K^+ and rarely, Na^+ are not typical of the groundwater of subtropical humid climate. Within the investigated territory the groundwater could be divided into two types - relatively pure shallow groundwater, formed primarily under the effect of natural factors and having a high content of NO_3^- but rarely K^+, Cl^-, SO_4^{2-}, in some sampling points; and relatively polluted shallow groundwater, characterized by significant changes of chemical composition due to intensive agricultural activity. This type has higher pH-values, concentration of main components, including NO_3^-, K^+, SO_4^{2-}, Cl^-, and, accordingly, value of total dissolved solids in comparison with relatively pure shallow groundwater.

1. Introduction

The largest freshwater lake in China – Poyang Lake – is a unique ecosystem. The Poyang Lake basin is not only a habitat for rare animal species, but also an important economic sector of Jiangxi Province. Resources of freshwater are used for domestic needs and industry, as well as for agriculture. Vast alluvial plains, surrounding Poyang Lake, have converted the basin into one of the main agricultural regions in China, where territories within the Poyang Lake catchment are often irrigated for rice and other crops cultivation.

Due to wide spread croplands, dense population and frequent shortage of centralized water supply and sewerage within the basin, the ecosystem is subjected to significant anthropogenic effect, in this case, shallow groundwater is not an exception. Furthermore, as long as the shallow groundwater is related to the Poyang Lake water, polluted groundwater may exert a negative influence on Poyang Lake. Therefore, comprehensive investigations of shallow groundwater chemical composition within the Poyang Lake area, in our opinion, are one of the priority targets of scientific research in this region. Investigation of shallow groundwater chemical composition formation allows estimating the influence of natural and anthropogenic factors on the existing ecosystem.

2. Materials and methods

2.1. *Study area*

The investigated area is situated in south-east China (Jiangxi Province) and is the part of the Poyang Lake catchment. It is one of the main hydrological subsystems of the Yangtze River. The area of the Poyang Lake catchment is 162225 km2 [1]. The investigated area belongs to the province of subtropical humid climate. The annual precipitation is 1400–2400 mm [2]. Irregular rainfall distribution during the year is controlled by the eastern-Asian monsoons. Wet season lasts from March – April to June, while further rainfall decreases from July to September and at, the same time, evapo-transpiration reaches its maximum, and after September the dry season is up to December. The relief of the investigated area is quite various from mountain alluvial plains in the relief depression areas to river valleys [3].

2.2 Sampling and analytical procedures

Hydrogeochemical analysis in the Poyang Lake catchment was conducted in November, 2011. The investigation target was shallow groundwater. 54 groundwater samples were retrieved from household wells in the investigated area. The sampling points are concentrated primarily to the north of Poyang Lake and on the territory of the Ganjiang River basin and the Xiushui River basin (figure 1).

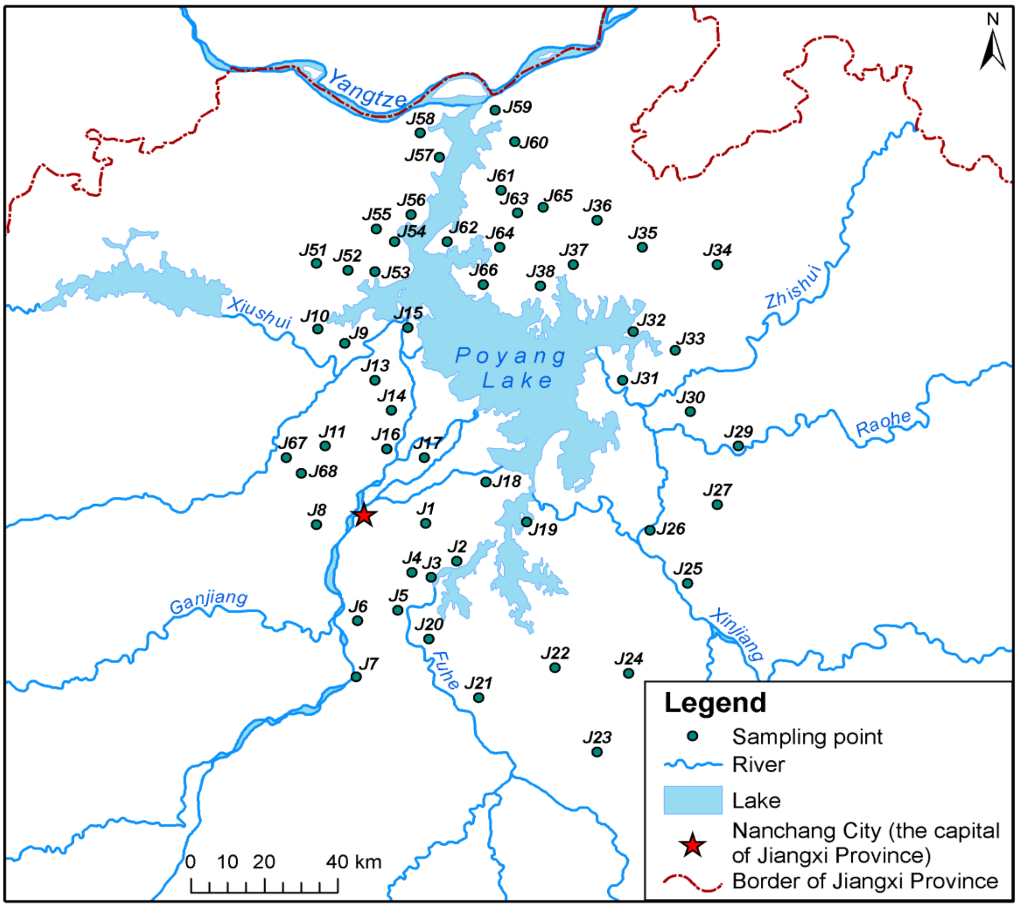

Figure 1. Scheme of the groundwater sampling points located in the Poyang Lake catchment.

One litre of water was collected in polyethylene bottles in each sampling point to determine the following ions- NO_3^-, PO_4^{2-}, Br^-, F^-. Electrical conductivity, temperature and pH were measured in situ. Chemical analysis of water samples was performed in the laboratory of China University of Geosciences (Beijing) using ion chromatography (Dionex-900) and titration method.

Based on the specific chemical composition of the latter and how sampling points are confined to territories of different economic and agricultural development, shallow waters were classified into various types.

3. Results and Discussions

Groundwater of the Poyang Lake area is basically ultra-fresh (TDS is up to 200 mg/L) and moderately fresh (TDS is 200–500 mg/L) while only in several sampling points TDS is more than 500 mg/L. The average value of TDS for investigated groundwater is 229 mg/L (table 1). Acid-alkaline properties of groundwater vary significantly, pH-value ranges from 4.75 to 7.26, i.e. geochemical conditions change from acid to neutral. The average pH-value is 6.20. pH -value increases parallel to the increase of TDS, whereas sharp pH increase could be observed in ultra-fresh waters and visa versa, decreases in waters with rather high TDS (figure 2).

Content	pH	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	TDS
Min.	4,75	3,25	1,36	1,23	0,10	1,77	0,23	1,04	0,58	24,0
Max.	7,26	353	148	102	206	98,2	31,6	52,7	57,4	768
Average	6,20	92,7	24,7	23,1	26,4	28,7	9,58	17,6	6,34	229

Table 1. Groundwater chemical composition of the Poyang Lake catchment, mg/L.

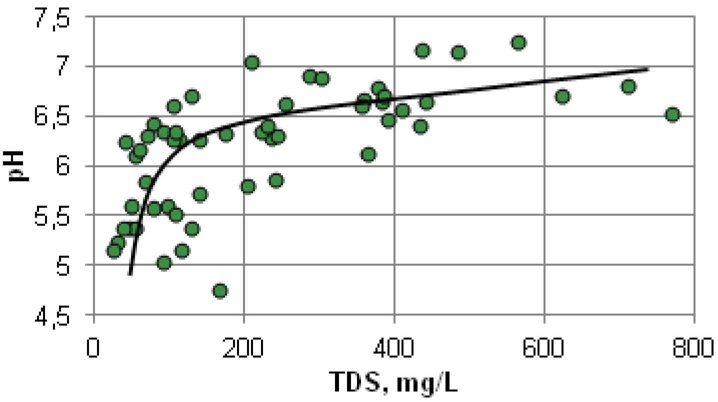

Figure 2. TDS versus pH-value in shallow groundwater of Poyang Lake catchment.

High concentrations of sulfate (SO_4^{2-}), chloride (Cl^-) and nitrate (NO_3^-) are observed, however, hydrocarbonate ion (HCO_3^-) is prevalent in investigated groundwaters. Increasingly relative average concentration of nitrate is registered in one third of the sampling points. Maximum concentration of NO_3^- (206 mg/L) is observed in point J11. TDS increase is related to the content increase of all anions (figure 3).

The groundwater of Poyang Lake area contains approximately equal concentrations of calcium (Ca^{2+}) and sodium (Na^+), 1,77 – 98.2 mg/L and 1.04 – 52.7 mg/L, respectively. In certain sampling points (J2, J3, J6, J11, J32) abnormal high content of potassium (K^+) is observed, ie. 57.4, 40.5, 39.0, 38.0 and 21.5 mg/L, respectively. Content of all cations increases consistently to TDS (figure 3). In ultra- fresh groundwater it is impossible to identify the dominant cation, while in water with TDS (up to 200 mg/L) the dominant cation is calcium. Such a phenomenon could be associated with the host rock composition, which controls the cationic composition of groundwater at the initial stage of chemical composition formation [4]. Magnesium (Mg^{2+}) behavior is specific with slight concentration, but obviously, decreases with the increase of TDS up to 600 mg/L (figure 4).

The formation of groundwater chemical composition in investigated area occurs under the influence of factors, both natural and anthropogenic ones. Within the investigated territory there are two types of shallow groundwater – relatively pure and conditionally polluted. Comparative analysis of these two types is shown in table 2.

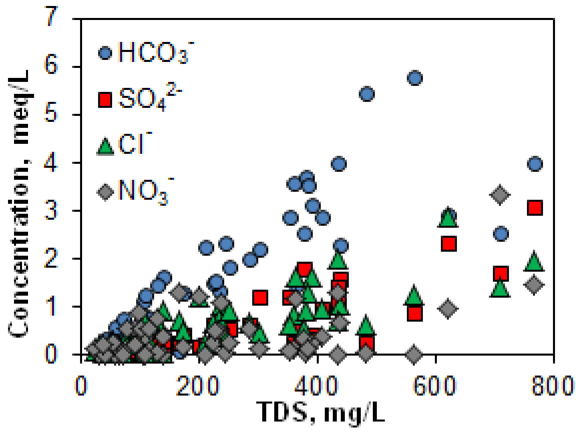

Figure 3. TDS versus content of main anions in the shallow groundwater of Poyang Lake catchment.

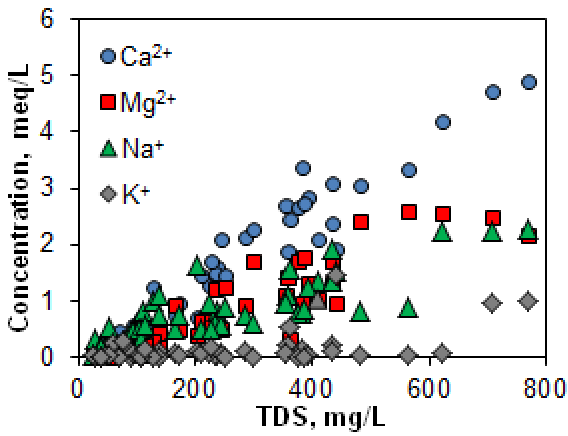

Figure 4. TDS versus content of main cations in the shallow groundwater of Poyang Lake catchment

Content	pH	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	TDS
Relatively pure shallow groundwater (32 sampling points)										
Min.	4.75	3.25	1.36	1.23	0.10	1.77	0.23	1.04	0.58	24.0
Max.	6.70	143	35.0	42.6	80.7	42.1	14.9	38.0	12.0	243
Average	5.87	36.8	8.57	12.1	19.4	11.4	3.86	11.0	2.73	106
Conditionally polluted shallow groundwater (22 sampling points)										
Min.	5.87	42.2	10.4	9.68	1.00	29.3	3,77	11.8	0.63	209
Max.	7.26	353	148	102	206	98.2	31,6	52.7	57.4	768
Average	6.68	174	48.0	39.0	36.7	53.7	17,9	27.2	11.6	408
Groundwater of tropical and subtropical humid climate province according to S.L. Shvartsev [4]										
Average	6.4	109	7.10	7.35	1.52	16.6	8.07	10.9	2.25	185
Poyang Lake (2 sampling points, according to results of field work carried out in October, 2013)										
Average	6.94	42.7	15.1	15.1	2.58	15.5	2.51	10.1	2.38	104

Table 2. Chemical composition of investigated groundwater types, mg/L.

Relatively shallow pure groundwater, presupposingly formed under the conditions of natural factors, is spread throughout the whole territory except in the north-eastern area. Conditional shallow polluted groundwater is largely localized in the north of the investigated area, as well as in the Ganjiang River basin and the Fuhe River basin to the south-west of Poyang Lake (figure 5).

Average concentrations of the major ions in relatively shallow pure groundwater are generally associated with the chemical groundwater composition of tropical and subtropical humid climate province (table 2). It should be noted that there is a sufficiently low content of HCO_3. The most significant average concentration is typical for nitrate-ion whereas the increased content of NO_3 can be observed to the south and to the west of the Poyang Lake (figure 5). There are also high concentrations of SO_4^{2-}, Na^+ and K^+. However, while increased SO_4^{2-}, Cl^- and Na^+ concentrations are point spread throughout the Poyang Lake area and, in most cases, are associated with each other, high K^+ concentrations are confined to the south-east of the investigated territory and are not associated with the increased concentrations of other chemical elements (figure 5). Increased NO_3 concentrations are best correlative with high Cl concentrations and in less degree with Na^+ (figure 5). The described type of shallow groundwater, in general, is associated with crust weathering process and the terrain, where agricultural activity is not widespread and, therefore, pollution embraces a pin-point pattern.

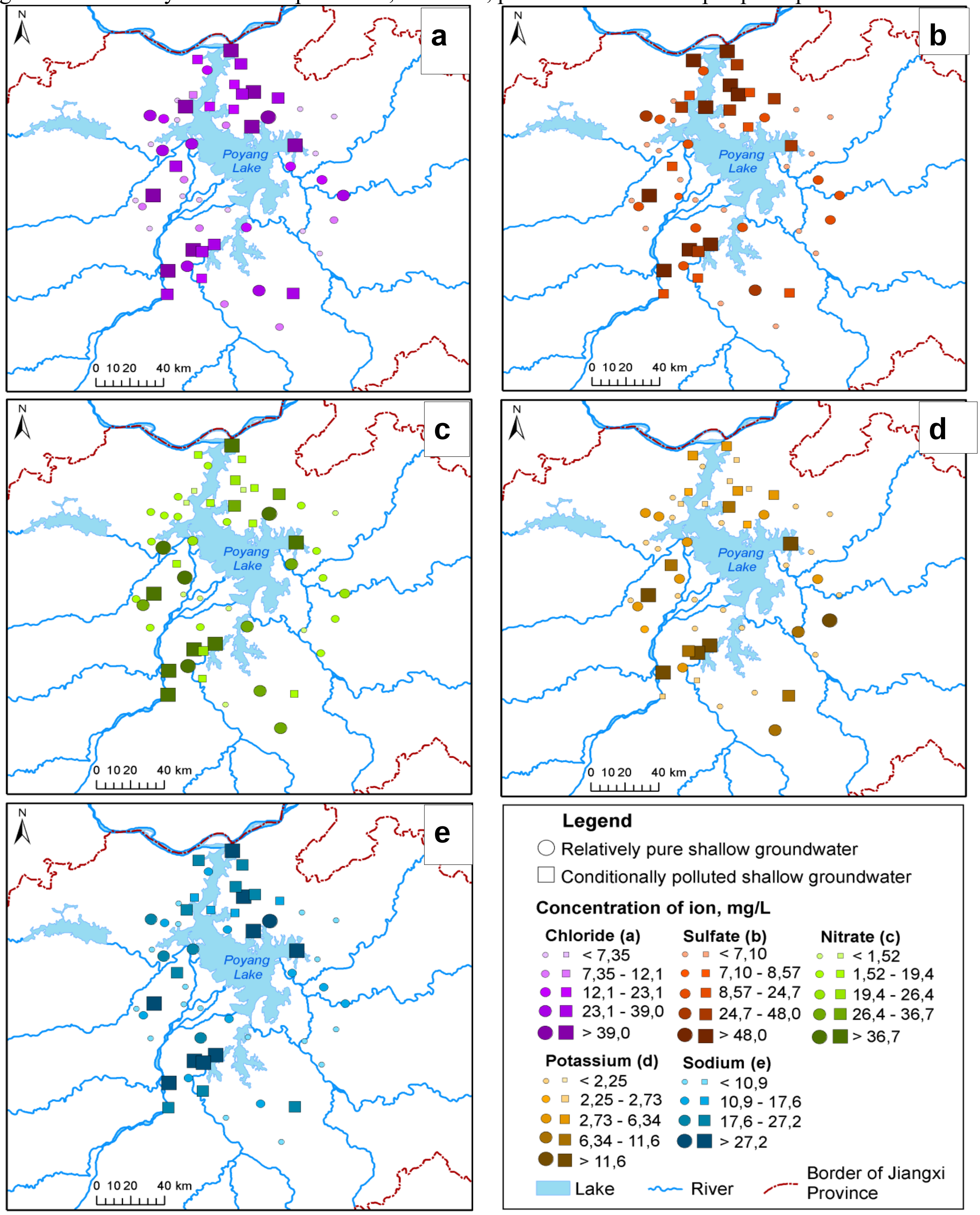

Figure 5. Abundance of Cl^- (a), SO_4^{2-} (b), NO_3^- (c), K^+ (d), Na^+ (e) in shallow groundwater of Poyang Lake catchment.

Conditionally polluted shallow groundwater is characterized by significantly high pH-values which correspond mainly to neutral conditions, in comparison to relatively pure shallow groundwater. The average concentrations of the major ions and TDS are several fold higher in comparison to those in the groundwater of tropical and subtropical humid climate province (table 2). Even minimum concentrations are high enough for some components. These features highlight the fact of significant groundwater pollution. This type is found within highly cultivated areas, where flood irrigation, paddy fields and fish pounds are prevalent. Based on A Perelman's concept, the authors suggest the term "agrolandscapes" to define such territories [5]. It should be noted that the sampling points situated to the west and to the south-west of Poyang Lake in the Xiushui, Ganjiang and Fuhe basins are characterized by significant concentration content of all analyzed components, in particular, Cl^-, SO_4^{2-}, NO_3^-, K^+, Na^+ (figure 5). However, to the north of Poyang Lake there is a wide-spread increase of Cl^-, SO_4^{2-} and Na^+ concentrations. Furthermore, concentrations of Cl^- и Na^+ are bound between themselves in most cases (figure 5). Obviously, the formation of groundwater chemical composition of the above-mentioned water types is connected with the intensification of agricultural activity, high dense population, and potentially with industrial production. This, in its turn, results in the accumulation of not only pollution agents, but also the increase of TDS and pH-value in this type of shallow groundwater.

4. Summary and Conclusions

Shallow groundwater of the Poyang Lake area is basically fresh, whereas pH-value varies widely, from 4.75 to 7.26, i.e. the geochemical environment changes from acid to neutral.

According to the conditions of groundwater formation within the Poyang Lake catchment, there are two main types of shallow groundwater – relatively pure shallow groundwater and conditionally polluted shallow groundwater. The first type, relatively pure shallow groundwater, is associated mainly with the natural site, crust weathering, and characterized by subacidic conditions, relatively low concentration of the major chemical composition components and TDS, and also extensive in-situ pollution. The chemical composition of this type is formed generally under the influence of natural factors, and the sampling sites are related with less agricultural and economically developed areas. The second type, conditionally polluted shallow groundwater, is characterized by neutral conditions. The pH-value growth is in accordance with TDS increase, and especially, with $NO3^-$, K^+, SO_4^{2-}, Cl^- concentration increase. It occurs in agricultural areas which are often irrigated for rice and other crops cultivation and characterized by widespread fish ponds. The chemical composition of this mentioned type indicates significant pollution, so its chemical composition is formed primarily under the effect of anthropogenic factors.

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