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Procedia Earth and Planetary Science 7 (2013) 373 – 376

Procedia
Earth and Planetary Science

Water Rock Interaction [WRI 14]

Hydrogeochemical characteristics of high As and high F groundwater in Hangjinhouqi, Hetao Plain, China

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Abstract

Hangjinhouqi is one of the most serious endemic arsenic and fluorosis areas in Hetao Plain, China. Groundwater samples (n=97) and two sediment cores issued from boreholes were collected to characterize the hydrogeochemistry of groundwater and sediment lithology of aquifers. Results showed that arsenic and fluoride content in groundwater range from 1 to 1093 μg/L and from 0.30 to 6.01 mg/L, respectively. The highest concentrations are mainly found in the flat areas of the Yin Mountains. As and F are not correlated, suggesting that their origin and/or geochemical processes leading to their release to groundwater are different. Between 15 and 45m of depth, both arsenic and fluoride are more easily released into groundwater. The external environment of high As and high F groundwater formation consisted of a lake-based geographical environment in a long term and closed geological structure, arid and semi-arid climatic conditions, as well as hydrogeological characteristics.

Selection and/or peer-review under responsibility of the Organizing and Scientific Committee of WRI 14 – 2013

Keywords: hydrogeochemistry; high arsenic and high fluoride groundwater; sediment lithology.

1. Introduction

High arsenic concentration in groundwater is one of the major environmental problems affecting dramatically both the human health and economic development. In China, over 2.3 million people mainly in Inner Mongolia, Shanxi Province, Xinjiang, Ningxia, Jilin Province and Anhui Province are affected by high dissolved arsenic content, and over 0.5 million people are drinking water with arsenic concentration higher than 50 μg/L [1]. Hetao Plain of Inner Mongolia is one of the most affected areas by endemic diseases of arsenic. Up to 0.3 million people have been affected by arsenic and the number

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Selection and/or peer-review under responsibility of the Organizing and Scientific Committee of WRI 14 – 2013
doi:10.1016/j.proeps.2013.03.053

troubled in endemic arsenium seriously has reached 2,000 [2]. This area is also affected by high fluoride content in groundwater. About 6 million people are at risk of fluoride poisoning and 1.7 million people are suffering from dental fluorosis. Most of attentions have been dedicated to Hangjinhouqi, which is located in the western Hetao Plain of Inner Mongolia, due to high arsenic (>10 μg/L) and high fluoride (>1 mg/L) concentrations in groundwater [3, 4].

In this context, our study aims at identifying the hydrogeochemical characteristics of groundwater displaying high As and high F in Hangjinhouqi. Lithology features of the sediment from aquifers were also analyzed to find its influence on chemistry composition of groundwater. These will be helpful for further understand sources and genesis of groundwater with not only high As but also high F.

2. Materials and methods

2.1. Study area

Hangjinhouqi, with an area of 1,767 km^2, lies in the hinterland of western Hetao Plain in Inner Mongolia. It is on the northern margin of the Yellow River, bounded to the north by the Yin Mountains (Fig.1). The climate is semi-arid to arid, with an average annual precipitation and evaporation of about 135.9 mm and 1,984 mm, respectively. Annual average air temperature is 7.5^{o}C. The terrain is elevated in the southwest and low in the northeast. Hangjinhouqi is located in a fault basin formed at the end of the Jurassic with fine sediments deposited in an inland lake. The Quaternary sediments are more than 500 m thick.

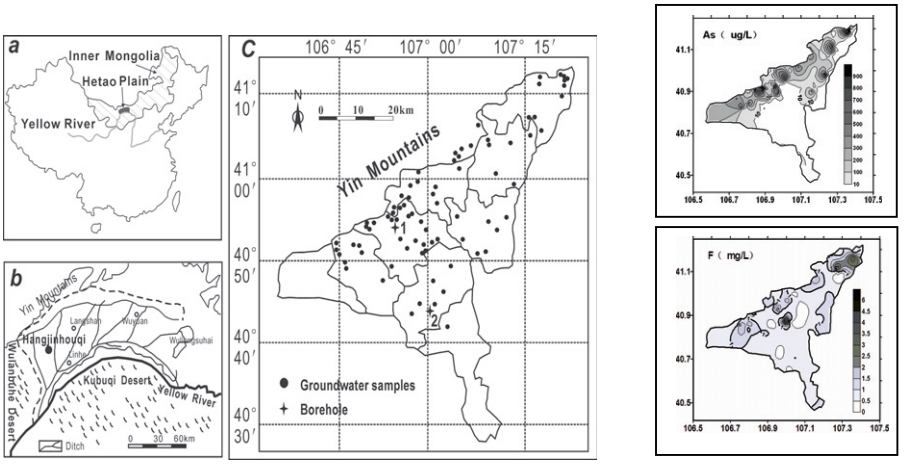

Fig.1. Maps showing the locations of Hetao Plain (a), Hangjinhouqi (b) and groundwater samples (c), as well as the distribution of arsenic and fluoride in groundwater of Hanjinghouqi.

2.2. Sampling and analysis

Groundwater samples were collected from hand-pumped (n=38) and motor-pumped (n=59) wells in Hangjinhouqi areas in November 2006 and August 2007, respectively (Fig.2). Electrical conductivity (EC) and pH were measured *in situ*. Alkalinity was determined using the Gran titration method within 24h after water collection. All groundwater samples were analysed for cation by ICP-AES (IRIS Intrepid II XSP, Thermo Electron Corporation) and anions by ion chromatography (IC) (DX-120, Dionex). Arsenic and

fluoride was quantified by hydride atomic fluorescence spectrometer of AFS830 and the fluoride ion-selective electrode method respectively.

Sediments were sampled from two boreholes of 50 m depth. Borehole 1 is located in the northwest where the endemic arsenic and fluorosis are severe, and Borehole 2 is located in the southeast where no endemic arsenic and fluorosis are found (Fig.1).

3. Results and discussion

3.1. Hydrogeochemical characteristics of groundwater and sedimentary lithology

Statistical results of chemical indicators of groundwater (Table 2) showed that pH and electric conductivity of groundwater ranges from 7.00 to 8.28 and from 189 to 13,630μs/cm, respectively. The dominant cation is Na^+, and the major anions are Cl^- and HCO_3^-. Arsenic and fluoride range from 1 to 1,093 μg/L and from 0.30 to 6.01 mg/L, respectively.

In borehole 1, from 0 to 10.5m depth, the sediment is mainly composed of silt, covered with mild clay and clay. Deeper, sediment is mainly grey brown or black medium and fine sand, interbedded with several layers of clay, which had high content of organic matters and intense rancid flavor. Over 30m of depth, sediment is grey brown medium and fine sand. In borehole 2, from 0 to 13.2m depth, the sediment is mainly composed of silt and clay interbedded with mild clay. Below 13.2m depth, there is fine sand presenting tawny where no brown and black sand was found.

3.2. Relationship of high arsenic and high fluoride in groundwater

The general distribution of arsenic and fluoride in groundwater samples (n=97) is shown in Figure 1. It appears that both the high As (>10μg/L) and high F (>1.0mg/L) mainly occur in the flat areas of Yin Mountains, where the groundwater flow conditions are generally slow due to low hydraulic gradient and abundant fine-grained sediments [4]. Furthermore, As and F are not correlated together (Fig 2.a; R^2 = 0.05) suggesting that their origin and/or geochemical processes leading to their release to groundwater are different.

3.3. High arsenic and high fluoride depending on depth

Results show that high fluoride and high arsenic concentrations in groundwater are found between 15 and 35m depth (Fig 2.b) and between 15 and 45m depth (Fig 2.c) respectively suggesting that As and F release is limited to upper part of the aquifer. However, only a few samples were collected below 45m depth, most of water samples being collected in upper part of the shallow aquifer (above 45 m deep).

Table 2. Hydrochemical analyses of groundwater. Chemical elements are expressed in mg/L except for As in μg/L

Index	Max.	Min.	Mean	Index	Max.	Min.	Mean	Index	Max.	Min.	Mean
pH	8.28	7.00	7.60	Ca	372.9	2.10	77.3	F	6.01	0.3	1.15
EC(μs/cm)	189	13630	3447	Mg	321.4	4.71	101.6	As	1093	1	250
ORP (mV)	136	-431	-85.7	SO_4	1551	0.01	297	DO (mg/L)	6.80	1.80	3.99
K	31.1	0.48	5.81	Cl	4531	36.7	613	NH_4	10.5	0.10	2.72
Na	1834	38.9	449.6	HCO_3	1290	243.8	590	DOC	12.9	2.31	5.48

Whatever, As and F concentrations in groundwater are strongly constrained by environmental conditions. In high arsenic/fluoride area, the cap rock composed of clay and mild clay prevented atmospheric O_2 intrusion and thus produced a reducing environment, which is proved by the high content of organic matters in clay and intense smelling if sulfides. Such conditions favor high arsenic concentrations. However, concerning fluorides, which are insensitive to redox conditions, other parameters, such as higher residence time of waters below the cap rock must be involved. By contrast, low arsenic and low fluoride content in are found in aquifers mainly composed of tawny fine sand in a weak oxidizing environment without any smelling of sulfides. The overlying layer composed of silt, clay and mild clay has poor sealing capacities favoring both intrusion of atmospheric oxygen and young waters.

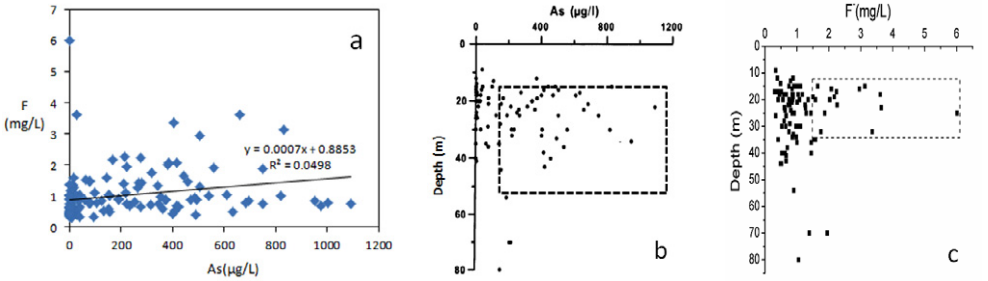

Fig. 2. Relationship of arsenic and fluoride in groundwater from Hangjinhouqi (a), as well as relationship of well depth and high arsenic/high fluoride groundwater (b, and c).

4. Conclusions

Arsenic and fluoride in groundwater from Hangjinhouqi range from 1.00 to 1,093 μg/L and from 0.30 to 6.01 mg/L, respectively. Both high As and F mainly occur in the flat areas of Yin Mountains, in the shallow aquifer between 15 and 45m of depth. They are not correlated together suggesting that their origin and/or geochemical processes leading to their release to groundwater are different. The external environment of high-arsenic groundwater formation consisted of lake-based geographical environment in a long term and closed geological structure, arid and semi-arid climatic conditions, and hydrogeological characteristics.

Acknowledgements

The research work was financially supported jointly by National Natural Science Foundation of China (40872157, 40830748), National Program on Key Basic Research Project of China (973) (2010CB 428802), Research Fund for the Doctoral Program of Higher Education (20110145110003), National High Technology Research and Development Program of China (863) (2012AA062602), Program for New Century Excellent Talents in University of Ministry of Education of China (NCET-07-0773) and the Fundamental Research Funds for the Central Universities (CUGL100501).

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