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Original Research Paper

The Pollution Characteristics Analysis of Groundwater in Sanjiao Area Hedong Coalfield

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ABSTRACT

The groundwater pollution is an increasingly serious problem in the world. There are abundant coal resources and coalbed methane resources in Sanjiao area, Hedong Coalfield. The exploitation of mineral resources has a pernicious influence on the local groundwater environment. The local shallow groundwater is the only drinking water source for local residents. So the analysis of the groundwater pollution characteristics is essential for maintaining drinking water safe for local residents. The results showed that NH_4^+, Cl^-, SO_4^{2-}, NO_3^-, F^-, NO^{2-}, Cr^{6+}, Fe, TDS, etc. have exceeded to varying degrees. The amount of methane in SX99 is very high, so it should take measures to release methane to reduce the methane concentration in groundwater.

INTRODUCTION

Groundwater quality evaluation aims to determine, whether the groundwater is good or bad and the groundwater degree. It is used to study the regional groundwater quality issues and the regional groundwater pollution, in particular. Sources of groundwater pollution include industrial pollutants, agricultural pollutants, domestic pollutants, mining pollution, natural pollutants, artificial recharge, etc.

Currently, groundwaters are contaminated by toxic chemicals, and are the most urgent situations in environmental protection in Europe, the United States, Japan and other developed countries. According to incomplete statistics, more than 56 million people have been influenced by groundwater pollution, in the investigation of shallow groundwater pollution in China's 661 cities. In recent years, the groundwater pollution has become one of the most important researches.

Hedong coalfield is located in Shanxi Province. There are abundant coal resources and coalbed methane resources. Upto now, there has been no study of shallow groundwater in the study area. The shallow groundwater in the region is the only drinking water source for the locals. With the utilization of coal resources and coalbed methane resources, it is imperative to study groundwater pollution in this area.

STUDY AREA

The study area is located in the middle of Hedong coalfield in Shanxi Province. It has a sub-arid continental monsoon climate featuring four distinct seasons. The mean annual temperature is 8.8°C. The mean annual rainfall is 518.8 mm and the mean annual evaporation is 2149.8 mm. Two major rivers, Qiushui River and Yellow River, flow though the area from the north to south. Qiushui River is a seasonal river. It has developed a valley landform and Loess hill landscape.

The emergence stratum mainly are Permian, Triassic and Quaternary. The Tertiary and Quaternary has an unconformable contact with the underlying strata. The Permian are widely outcropped in the whole study area. The Triassic are only outcropped in the northwest of Sanjiao Town. The area is in the west wing of Lvliangshan anticlinorium. The tectonic is simple, which is a monoclinal structure, west dip. There are two major faults in the study area, one in the northeast and other in the south.

The shallow groundwater is classified into two types, that is, the shallow weathering fissure water and the tectonic crack water in sandstone. The shallow groundwater is the main drinking water source (Lian Huiqing 2013). The groundwater flow with the formation dip direction. In the middle, the flow is from southeast to northwest, and in the south of Qikou the flow is from east to west (Ji Zhou et al. 2013, Yang Yongtian 2007). Through the analysis of hydrogeological conditions, the relationship between shallow groundwater and rivers is that the groundwater recharges to the rivers (Gao Baoyu et al. 2008, Wei Xiaoou et al. 2012).

SAMPLING

In this study, 67 samples abstracted from wells and springs within the fractured bedrock were collected in June, 2012 for the analysis of the groundwater quality.

The field sampling methods and sample retention refer-

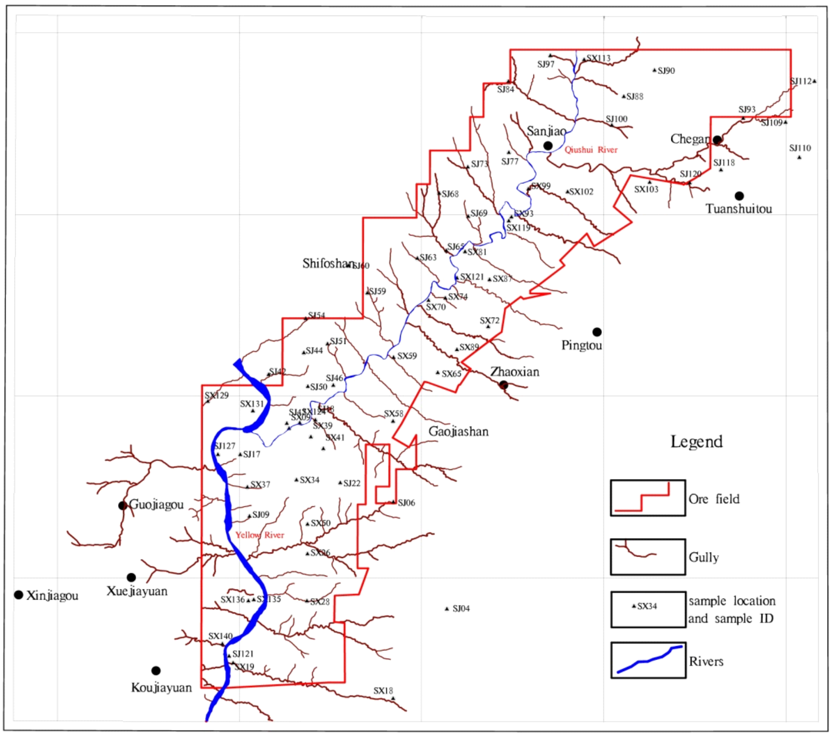

Fig. 1: Map showing the location of the sampling stations.

ence the water quality sampling and technical regulation of the preservation and handling of samples set by the Ministry of Environmental Protection of the People's Republic of China. Fig. 1 shows the location of the study area and the sampling locations in the study area. The collected samples were analysed for a total of 34 water quality variables, including pH, total hardness, TDS, SO_4^{2-}, NO_3^-, NO_2^-, NH_4^+, F^-, Cl^-, As, Cr^{6+}, Fe, Mn, Cu, Zn, I^- and CH_4.

SHALLOW GROUNDWATER QUALITY ANALYSIS

According to the standard level III in Quality Standard for Groundwater (GB/T 14848-93), the standard index method is applied to evaluate the groundwater quality using the test value as parameters of groundwater water quality in the study area.

$$Pi=\frac{C_i}{C_{oi}} \quad Pi=\frac{C_i}{C_{oi}}$$

where, P_i - single factor pollution index of the ith evaluation factor; C_i - measured concentration of the ith evaluation factor, mg/L; C_{oi} - evaluation criterion of the ith evaluation factor, mg/L.

For pH, the standard index can be calculated with equation as follows:

$$S_{pHj}=\frac{7.0-pH_j}{7.0-pH_{Sd}} \quad S_{pHj}=\frac{7.0-pH_j}{7.0-pH_{Sd}} \qquad (pH_j \le 7.0)$$

$$S_{pHj}=\frac{pH_j-7.0}{pH_{SU}-7.0} \quad S_{pHj}=\frac{pH_j-7.0}{pH_{SU}-7.0} \qquad (pH_j > 7.0)$$

Where, S_{pHj} - pH standard index at J point; pH_{Sd} - lower limit of pH value in Quality Standard for Groundwater; pH_{SU} - upper limit of pH value in Quality Standard for Groundwater; pH_j - the mean value of pH at J point .

The situation that *Pi* less than 1, is satisfying Quality Standard for Groundwater. *Pi* more than 1 shows that the groundwater quality exceeds the standard and will bring detrimental effect on the health.

The results are derived according to the above-mentioned equations. A part of the results of the calculations are depicted in Table 1.

POLLUTION CHARACTERISTICS ANALYSIS OF GROUNDWATER

The results show that, NH_4^+, Cl^-, SO_4^{2-}, NO_3^-, F^-, NO_2^-, total hardness, TDS, Fe, Cr^{6+} have exceeded the standard values to varying degrees.

In the most parts of the study area, the chloride satisfied the standards except for SX124, SX135, SX121. The excessive chloride is mainly located near the river. During the investigation, the phenomenon is found that the nearby residents push the domestic waste and domestic sewage into the river and the waste contained amount of chlorides. So the human activity is the main cause of excessive chloride.

The area between Sanjiao and Qikou is seriously polluted by F^-, especially nearby the Qiushui River. In rest of the area there is no F^- pollution. Referring to "Analyses of Unsafe Factors of Rural Drinking Water in Lvliang City", F^- pollution is caused by natural reasons. In the history of Yellow River development, salt enriched in the low-lying areas along the Yellow River. It is related with F^- pollution. The mineral accumulation carried by the river made F^- content in soil, rock and groundwater high.

The area that TDS exceeds the Standards, is located mainly on both sides of the Yellow River and Qiushui River. And the groundwater is seriously polluted at SX124. High TDS is caused by both natural reasons and human activities. In the history of Yellow River development, salt enriched in the low-lying areas along the Yellow River. It formed local high salt levels in the soil and groundwater. Besides, residents near rivers discharged pollutants into the rivers, caused the ion content in water to increase, and led TDS in the groundwater to exceed.

The samples which have an excessive Cr^{6+} include SJ17, SX37, SJ22, SX129, SJ50, SJ54, SJ59, SX72 and SJ68. Among these, SJ17 is the most seriously polluted. According to the analysis of groundwater runoff, high Cr^{6+} content in groundwater is mainly because groundwater flows through chromium-rich rock. In addition, during investigation it was found that, a local small leather workshops discharges the wastewater containing large amounts of Cr^{6+}, which results in the high Cr^{6+} content of the nearby groundwater.

The samples which have an excessive total hardness is mainly distributed on the sides of the river. And SJ129 is the most seriously polluted. There are three main reasons for total hardness pollution which are as follows: The biodegradation of domestic sewage, garbage and organic material in the soil; salt effect; the cation exchange capacity caused by salt pollution.

The Fe content at SJ69 and SX18 is exceeding the standards. This is because the pipe that the well is using is made up of iron. As a long-term effect of this, the Fe content in groundwater will increase.

The samples with excessive sulphate is mainly distributed near the Yellow River and in the west of the Yellow River in the south of Linjiaping. SX129, SX135, SX19 are seriously polluted. Because the polluted samples are the micro-porous water of loose sediments, so the sulphate exceeds due to river pollution.

The samples with excessive nitrate are widely distributed in the region and concentrated around the Qiushui River. In the Loess hilly region, local residents use chemical fertilizers in the course of cultivation. Nitrogen in fertilizers leach into groundwater after rainfall and cause the nitrate content in the groundwater to increase. The nitrate pollution nearby rivers is due to the river pollution. Distribution characteristics of nitrite and ammonia are similar with nitrate and less seriously polluted.

CH_4 CONTENT ANALYSIS IN GROUNDWATER

At present there is no standard for methane concentrations in groundwater, and there has been limited relevant research on this (Gunter et al. 1997, Zhou et al. 2005). U.S. surface mining reclamation and the executive office has prepared a United States surface mining reclamation and in 1977 the executive office has prepared technical regulations about investigation and remediation of disordered discharge of methane in coal mining area. In the regulations, the action level of methane in different concentration is stated.

1. When the dissolved methane concentrations in groundwater exceed 28 mg/L, the methane released from groundwater may explode or burn in a confined space. In this situation, a variety of measures, such as ventilation, should be applied to make methane spread as soon as possible in order to reduce risks.
2. When the dissolved methane concentrations in groundwater exceed 10 mg/L, the methane in groundwater may slowly accumulate. It is needed that the warning should be provided and measures should be taken to reduce methane.
3. When dissolved methane concentrations in groundwater is less than 10 mg/L, there is no need to take immediate action. Testing methane content in groundwater should be taken regularly to ensure safety.

Table 2 shows that the methane content at SX99 is clearly different from other samples. According to the investigation, SX99 is a deep drill hole down to the limestone of the Taiyuan formation, the water head was above the surface, and later the well was sealed. The methane content at SX99 is much higher than other shallow samples. It is indicated that SX99 has poor sealing and has close hydraulic connection with the coal layers. So SX99 should take steps to release methane to reduce the methane content.

CONCLUSIONS

The following conclusions could be drawn after the study and analysis of shallow groundwater investigation in the study area:

1. NH_4^+, Cl^-, SO_4^{2-}, NO_3^-, F^-, NO_2^-, total hardness ,TDS, Fe, Cr^{6+} in shallow groundwater have exceeded the

Table 1: The results of the calculation of the shallow groundwater in the study area.

ID	NH_4^+	Cl^-	SO_4^{2-}	NO_3^-	F^-	I^-	NO_2^-	Total hardness	TDS	As	Cu	Zn	Fe	Mn	Cr^{6+}	pH
The micro-porous water of loose sediments																
SX09	2.5	0.72	1.19	4.31	0.92	0.1	0.26	1.13	1.1	0.02	0	0	0.2	0.19	0	0.27
SX113	0	0.29	0.47	4.41	0.6	0	19.6	0.86	0.8	0	0	0	0.09	0.03	0	0.41
SX119	0	0.62	0.94	14.63	0.48	0	60	1.48	1.18	0	0	0.02	0.09	0.01	0	0.53
The weathering fissure water of fragmental rock																
SX18	0	0.35	1.28	2.42	1	0.15	0.68	0.87	1.05	0.02	0	0	2.01	0.24	0.4	0.57
SX58	0	0.13	0.61	2.5	0.6	0	0.6	0.52	0.7	0.02	0	0	0.07	0.01	0.24	0.53
SX81	0	0.28	0.35	4.02	1.7	0	0.62	0.66	0.57	0	0	0	0.45	0.04	0.08	0.27
SX87	0	0.07	0.3	0.5	1.2	0.1	0.48	0.28	0.47	0.04	0	0	0.07	0	0.48	1.06
SX99	5.5	0.67	0.24	0.06	3.5	0	0	0.02	0.67	0	0	0.02	0.59	0.15	0	1.07
SX129	0	0.48	1.17	1.81	0.8	0.15	15.6	0.83	1	0.04	0	0.01	0.17	0.18	1.2	0.52
SJ17	0	0.85	1.88	1.47	0.66	0.2	0.1	1.3	1.31	0	0	0	0.47	0.04	3	1.13
SJ18	4	0.25	0.8	0.2	1.2	0.2	0.24	0.49	0.81	0	0	0	0.25	0.02	0	0.71
SJ42	0	0.26	0.9	2.16	1.7	0	1.6	0.57	0.72	0.04	0	0	0.43	0.03	0	1.15
SJ46	0	1.08	1.69	2.14	2.2	0	0.72	0.67	1.44	0	0	0	0.09	0	0	1.18

Table 2: The methane content in shallow groundwater in the study area (μg/L).

ID	CH_4	ID	CH_4	ID	CH_4	ID	CH_4	ID	CH_4	ID	CH_4	ID	CH_4	ID	CH_4
SX09	0.1	SX50	0.42	SX89	0.52	SX121	1.13	SJ09	0.44	SJ51	0.16	SJ84	0.13	SJ118	0.19
SX18	0.37	SX58	0.77	SX93	0.94	SX124	0.9	SJ17	0.37	SJ54	<0.1	SJ88	<0.1	SJ120	0.13
SX19	0.14	SX59	1	SX99	1435	SX129	0.54	SJ18	0.1	SJ59	0.42	SJ90	0.48	SJ121	0.13
SX26	<0.1	SX65	0.49	SX102	34	SX131	0.37	SJ22	<0.1	SJ60	1.57	SJ93	<0.1	SJ127	0.1
SX28	0.75	SX70	0.29	SX103	3.94	SX135	0.66	SJ42	<0.1	SJ65	<0.1	SJ97	<0.1	0	0
SX34	0.12	SX72	0.1	SX111	2.36	SX136	0.25	SJ44	0.47	SJ68	0.49	SJ100	0.15	0	0
SX37	<0.1	SX74	1.01	SX113	0.56	SX140	0.5	SJ46	0.33	SJ69	0.55	SJ109	0.1	0	0
SX39	1.13	SX81	1.57	SX115	0.19	SJ04	0.38	SJ47	<0.1	SJ73	<0.1	SJ110	0.4	0	0
SX41	0.75	SX87	3.38	SX119	0.94	SJ06	0.38	SJ50	<0.1	SJ77	<0.1	SJ112	0.3	0	0

standard to varying degrees in the study area.

2. Cl^-, TDS, Cr^{6+}, total hardness, NO_3^-, NO_2^-, NH_4^+ pollution is scattered and F^- pollution is widely distributed in the study area.
3. Shallow groundwater pollution is mainly located on both sides of the rivers. Human activities are also concentrated on both sides of the rivers, so the main reasons of shallow groundwater pollution are polluted rivers and human activities.
4. The vast majority of shallow groundwater has lower methane content in the study area, but the methane content at SX99 is more than 10 mg/L. So measures should be taken to reduce methane content and environmental risk.
5. It is necessary to pay attention to rural drinking water and groundwater pollution in water-deficient areas and rich in minerals.

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