Advances in Engineering Research, volume 184
2nd International Conference on Sustainable Energy, Environment and Information Engineering (SEEIE 2019)

Geothermal Water Quality Assessment Based on Entropy Weighted TOPSIS Method in Xi'an, China

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***Abstract*—Reasonable and objective geothermal water quality assessment can provide a scientific basis for the development and utilization of geothermal water resources. Based on the chemical data of the Quaternary sediment reservoir (Q) and the Lantian-Bahe Group (LB) in Xi'an, the entropy weighted TOPSIS method was used to evaluate the water quality of geothermal water. The results show that the chemical indices (except for TH) of the LB geothermal water exceed the standard with poor quality. For the geothermal water of the Q, only NH_4^+ and F^- exceed the standard. The excessive NH_4^+ and F^- are due to human activities and the dissolution of fluoride bearing minerals, respectively. Comprehensive assessment based on TOPSIS evaluation model also reveals the geothermal water quality of the Q is better than that of the LB. Besides, the entropy weighted TOPSIS method has good applicability in the quality assessment of geothermal water.**

Keywords—geothermal water; water quality assessment; entropy weighted TOPSIS method; Xi'an

I. INTRODUCTION

Geothermal resources which have been widely used for the tourism, health care, realty industry, agriculture, and fisheries, have achieved good social and economic benefits with good development prospects [1-3].

Xi'an city is located in the south-central Guanzhong Basin, and it has abundant geothermal resources with over 160 geothermal wells. The annual exploitation of geothermal water is about 4×10^6 m^3 [4]. However, in recent years, Xi'an City has lagged behind in scientific planning and rational use of geothermal resources, resulting in some problems, such as the low level of geothermal resources utilization and the environmental problems [4-5].

The environment of geothermal reservoir is a complex system that is very susceptible to the fragility of hydrogeological conditions and the human exploitation activities. At present, the quality evaluations of medical hot mineral water, fishery water, agricultural irrigation water, and corrosion geothermal water are mainly carried out to provide theoretical guidance for the rational utilization of geothermal water [5-6]. However, the comprehensive assessment of geothermal water quality is relatively rare.

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method has been extensively used in many fields to solve multiple-attribute decision making problems [7], such as water resource decision making [8], surface water quality assessment [9] and groundwater quality assessment [10]. With the development of the TOPSIS theory and application, the advantages of entropy weighted TOPSIS method is to avoid the uncertainty and randomness of the optimal selection results [11].

In this study, the entropy weighted TOPSIS method is applied to the assessment of geothermal water quality in Xi'an, and to verify the applicability of this method.

II. STUDY AREA

The Xi'an geothermal field is mainly located between the south bank of the Wei River and the Qinling Mountains with an area of about 1300 km^2 (Figure I). The Qinling Mountains is the major recharge area of Xi'an geothermal water [12]. The flow direction is from south west to north east [4]. The largest discharge of Xi'an geothermal water is artificial extraction, followed by runoff and hot spring activity. Xi'an geothermal reservoirs are mainly divided into three categories: the Quaternary sediment reservoir, the Neoproterozoic and Paleogene thermal reservoir (including Zhangjiapo Group, Lantian-Bahe Group, Gaoling Group, and Bailuyuan Group), and the Proterozoic thermal reservoir. Among them, the Lantian-Bahe Group is the main thermal reservoir in this area.

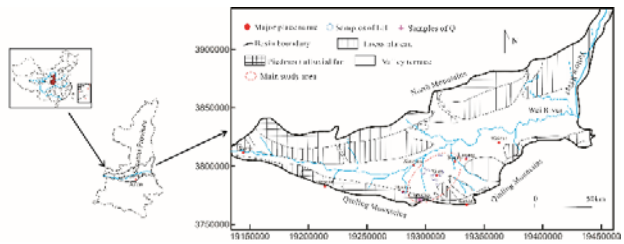

FIGURE I. SIMPLIFIED GEOGRAPHIC MAP WITH SAMPLING LOCATIONS

III. MATERIALS AND METHODS

A. Materials

To carry out the study, 28 water samples were collected in Xi'an, including 15 samples of Lantian-Bahe Group (LB), and 13 samples of the Quaternary sediment reservoir (Q). Depending on the standard for groundwater quality (GB14848-2017), the indices of each geothermal water sample used for assessment mainly included Cl^-, SO_4^{2-}, Na^+, NH_4^+, F^-, TDS and total hardness (TH). The TDS was tested on site using a portable multiparameter meter, and other parameters were measured in laboratory.

B. TOPSIS Method

The specific steps of TOPSIS method assessing water quality can be expressed as follows [7, 10, 13]. First, the initial decision matrix is constructed and normalized. Next, the weight for each index is determined, because the parameters contribute differently to water quality assessment. Then, the weighted standardized decision matrix is established. Later, positive and negative ideal reference points are determined. They represent the optimal and worst water quality of weighted standardization index, respectively. Following this, we determine the distances to the positive and negative ideal reference points. Finally, the closeness coefficient is calculated. The bigger the value of closeness coefficient, the better the groundwater quality is.

IV. RESULTS AND DISCUSSION

A. Single Parameter Assessment

The water quality of single parameter assessment for geothermal water is shown in Table I. These parameters chosen are all important for assessing geothermal water quality. Rank I, II, III, IV, and V represent excellent quality water, good quality water, medium quality water, poor quality water and extremely poor quality water, respectively.

TDS, SO_4^{2-}, Na^+, and NH_4^+ of the Lantian-Bahe Group samples belong to the ranks of III, IV, or V. Moreover, the proportion of rank V is as high as 26.7-60.0%. Cl^- of the LB includes five ranks, and IV and V ranks account for 60%. What is more, the proportion of F^- in rank V is 100%, which seriously exceeds the standard. TH is in the ranks of I, II, and III, and the proportion of I rank reaches 73.3%. In general, the geothermal water of the LB is poor quality and is not suitable for human direct use without treatment. For geothermal water samples of the Quaternary sediment reservoir, TDS, TH, SO_4^{2-}, Na^+, and Cl^- are I, II or III rank of water quality. The 30.8% of samples contain IV rank of NH_4^+, and the 76.9% of samples contain V rank of F^-.

It can be seen that the water quality of the Q is better than that of the LB. The main reason is that the reservoir of the Lantian-Bahe Group with the greater depth and the higher temperature has strong water-rock interaction, which results in high concentration of the parameters. However, the high F^- concentration in these two reservoirs exceeds the standard severely, which is mainly due to the dissolution of fluorine minerals. Besides, the high concentration of NH_4^+ is influenced by human activities. The large-scale exploitation of geothermal water causes the leaking recharge from the shallow contaminated groundwater to the deep aquifers because of the intensive interaction of the water pumping well.

B. Comprehensive Assessment of Geothermal Water

The indexes of geothermal water are normalized. The information entropy and entropy weight of each index are obtained (Table II). From Table II, the weights of F^- and NH_4^+ are relatively larger. The *CC* values of groundwater standard (Table III) are obtained by TOPSIS method based on entropy weight, which provides a basis for the classification of groundwater quality.

The results of comprehensive assessment of geothermal water are listed in Table IV. And percentages of water quality rank for geothermal water samples are shown in Figure II. It can be revealed from Figure II that there are only IV and V ranks of water quality in the LB geothermal water, accounting for 66.7% and 33.3% respectively. Compared with the LB geothermal water, the quality of the Quaternary geothermal water is better, with 15.4%, 30.8%, 46.1% and 8.7% of I, II, III, IV ranks water quality, respectively.

In the vertical direction, the geothermal water has the evolutionary characteristics of the water quality exceeding the standard with the increase of the buried depth. Hence, the geothermal water of the LB cannot be used as drinking water. Besides, the geothermal water easily pollutes the surrounding environment, if it is discharged directly without treatment. However, the geothermal water in some areas of the Q could be available for human drinking because of its excellent water quality.

V. CONCLUSION

In this study, the single index evaluation shows that all of the hydrochemical indices (except for TH) of the LB samples do not meet the standards. For the Quaternary geothermal water, only NH_4^+ and F^- exceed the standard. NH_4^+ is mainly caused by the interaction of geothermal wells which make the contaminated shallow groundwater flow into the thermal reservoir. The dissolution of fluorine minerals mainly contributes to the high concentration of F^-.

Based on the comprehensive assessment results, the geothermal water has the evolutionary characteristics of the water quality exceeding the standard with the increase of the buried depth in Xi'an. The geothermal water is discharged directly without treatment, which can result in the pollution to the environment. In addition, the TOPSIS method based on entropy weight has good applicability in the quality assessment of geothermal water.

TABLE I. PERCENTAGE OF WATER QUALITY RANKS FOR SINGLE PARAMETER ASSESSMENT RESULTS

Rank		TDS	TH	SO_4^{2-}	Cl^-	Na^+	NH_4^+	F^-
LB	I	0.0	73.3	0.0	6.7	0.0	0.0	0.0
	II	0.0	13.3	0.0	20.0	0.0	0.0	0.0
	III	40.0	13.3	46.7	13.3	6.7	33.3	0.0
	IV	13.3	0.0	6.7	40.0	33.3	40.0	0.0
	V	46.7	0.0	46.7	20.0	60.0	26.7	100.0
Q	I	53.8	84.6	15.4	92.3	61.5	15.4	23.1
	II	46.2	15.4	53.8	7.7	30.8	15.4	0.0
	III	0.0	0.0	30.8	0.0	7.7	38.5	0.0
	IV	0.0	0.0	0.0	0.0	0.0	30.8	0.0
	V	0.0	0.0	0.0	0.0	0.0	0.0	76.9

TABLE II. THE INFORMATION ENTROPY AND ENTROPY WEIGHT OF EACH INDEX

Index	TDS	TH	SO_4^{2-}	Cl^-	Na^+	F^-	NH_4^+
ej	0.016	0.025	0.017	0.016	0.017	0.027	0.029
ω_j	0.107	0.170	0.117	0.109	0.114	0.185	0.198

TABLE III. CC VALUES OF THE STANDARD FOR GROUNDWATER QUALITY

Standard	I	II	III	IV	V
CC	≥0.9168	≥0.8500	≥0.7812	≥0.6749	<0.6749

TABLE IV. COMPREHENSIVE ASSESSMENT RESULTS OF GEOTHERMAL WATER QUALITY

Label	*CC*	Rank	Label	*CC*	Rank
LB1	0.6927	IV	Q1	0.7997	III
LB2	0.4574	V	Q2	0.8027	III
LB3	0.7472	IV	Q3	0.8094	III
LB4	0.6376	V	Q4	0.8646	II
LB5	0.7563	IV	Q5	0.8379	III
LB6	0.6909	IV	Q6	0.9189	I
LB7	0.7129	IV	Q7	0.8437	III
LB8	0.7459	IV	Q8	0.7807	IV
LB9	0.7692	IV	Q9	0.8148	III
LB10	0.7258	IV	Q10	0.9023	II
LB11	0.7007	IV	Q11	0.8959	II
LB12	0.2564	V	Q12	0.9237	I
LB13	0.7595	IV	Q13	0.8857	II
LB14	0.6570	V			
LB15	0.3466	V			

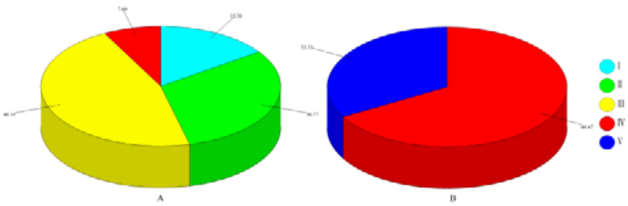

FIGURE II. PERCENTAGE OF WATER QUALITY RANKS FOR GEOTHERMAL WATER SAMPLES: (A) SAMPLES OF THE QUATERNARY SEDIMENT RESERVOIR AND (B) THE SAMPLES OF LANTIAN-BAHE GROUP.

ACKNOWLEDGMENT

This study is financially supported by the National Natural Science Foundation of China (Grant No. 41572236). And the contributions of all authors are also gratefully acknowledged.

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