Comprehensive Evaluation of Groundwater Quality in Tailings Pond of a Mine in Southwest China

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Abstract

The bayesian theory was introduced into the groundwater quality evaluation system and a groundwater quality evaluation model was built accordingly. A mine tailings pond in southwest China was taken as the object, and the monitoring results of 10 groundwater quality monitoring sites in the study area were used for practical application combined with the bayesian model. It shows that the calculation of the bayesian model is simple, and the results can reflect the current situation of groundwater quality in the tailings pond of the mine more comprehensively than those of the single factor evaluation method, which is worthy to be popularized and applied.

Keywords

Bayesian method; mine tailings pond; groundwater quality evaluation.

1. Introduction

Mining is the most important ancient industry in the world, and the tailings and slag produced in mining are the main factors of groundwater pollution [1].Therefore, environmental protection of groundwater in mining areas has become an instant necessity. The groundwater environment in mining areas can be observed in time through water quality assessment. Once the results show that the groundwater in the mine is polluted, corresponding measures can be taken instantly in prevention of more serious damage to the groundwater environment. Since results of appropriate analysis and evaluation can provide effective information for scientific mine treatment, comprehensive evaluation of groundwater quality in mining areas is a basis for the protection of groundwater environment [2]. Usually, several methods are used to evaluate water quality both in groundwater and mining areas such as single factor evaluation method [3], fuzzy comprehensive evaluation method [4], grey relational degree method [5] and so on. Among them, the single factor method is simple and direct, without calculation, but it cannot evaluate the quality of groundwater comprehensively; the comprehensive fuzzy rating method has high reliability, but the calculation steps are sophisticated. Once the samples or evaluation indexes appear in relatively large quantity, the evaluation can be very difficult [6].

Bayesian theory is a mathematical statistical method based on probability, which contains subjective interpretation of probability and provides a simple and effective method to transform prior probability into posterior probability in the case of new information addition [7]. Therefore, this paper takes the groundwater in tailings pond of a mine in Southwest China as the object, uses the bayesian method to evaluate the groundwater quality in the mining area and discusses effective methods to evaluate groundwater quality in the mining area comprehensively.

2. Materials and Methods

2.1 An Overview of Study Area

The study area is located in the northern slope area of the leidashi mountain at the south of longzhou mountain in the south of southwest of Sichuan, and the north of the yunnan-guizhou plateau, which is of erosion depositing, erosion and denudation structure, characterized by mountain, high valley and deep basin staggered distribution. The evaluation region is of south Asian tropical monsoon climate, with an average annual precipitation of 1097.6mm and evaporation of 2405.5mm, belonging to the anning river basin, where valleys develop in mining areas and form the mountain valley landforms which are high in the west and low in the east. In this region, regional distribution from the Archean to Cenozoic strata can be found. Besides, metamorphic rock, carbonate rock and magmatic rock are all in growth there. The study area is located in the panxi rift zone, which is in the geotectonic position of kang dian floor middle axis with the central axis off to the east. We consider it an extremely complex geological structure with intense neotectonic movement, in which mainly formed a series of NW-NWW, S-N faults. The study area is mainly distributed with the fracture water of metamorphic rock and magmatic rock, followed by Interstitial water in pores and fissures of clastic rock while the pore water of loose accumulation and crevice water in carbonate rocks is only distributed in local areas. The recharge of groundwater mainly comes from meteoric precipitation. After water quality test, it is proved that there're two types of water in the recharge area: calcium potassium sodium bicarbonate and calcium magnesium bicarbonate. Besides, the runoff area has the same hydrochemical characteristics as the recharge area. The downstream of the tailings pond is proved to be calcium magnesium bicarbonate and sodium calcium chloride sodium bicarbonate water, which is located in the area of groundwater discharge near the bank of the Anning River.

2.2 Monitoring Indexs

In the study area, the main aquifer is bedrock fissure aquifer. According to its hydrogeological conditions and engineering characteristics, 10 groundwater monitoring points were set up in the study area with monitoring items for total hardness, nitrate, nitrite, sulfate, chloride, fluoride, arsenic, ammonia nitrogen, CODmn, TDS and nickel. The sampling and analysis methods are in accordance with the the relevant provisions of groundwater environmental quality (GB/T14848-2017) and the drinking water standard testing method (GB5750).

Table 1 Detection data of groundwater quality in stope and tailings pond area of a mine in southwest China

Detection value	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10
sulfate	55.8	60.5	168	585	405	141	34.5	18.5	40.7	34
COD_{mn}	0.61	6.9	0.5	0.5	0.83	0.5	0.85	1.34	0.5	0.5
ammona nitrogen	0.027	0.78	0.004	0.15	0.13	0.096	0.14	0.034	0.027	0.12
nitrite	0.011	0.45	0.008	0.011	0.011	0.012	0.012	0.011	0.009	0.009
nitrate	0.011	0.89	0.02	0.024	0.024	0.028	0.024	0.28	0.024	0.028
fluoride	0.99	12	1.46	0.92	0.86	0.67	0.44	0.56	0.61	0.36
arsenic	0.0004	0.131	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004	0.0004
nickel	0.00199	0.04039	0.00394	0.00383	0.00316	0.006	0.08385	0.0009	0.00328	0.00319
total hardness	154	674	252	678	651	295	184	63.3	168	194
TDS	352	1380	518	1124	1146	540	378	207	333	385
chloride	10	35.6	14.8	24.9	23.7	10	14.2	10	10	20.9

The single factor evaluation is the basic method recommended in groundwater environmental quality (GB/ T14848-2017). This method is to compare the measured value of each monitoring point with the corresponding standard value of indexes in groundwater environment quality (GB/ T14848-2017), so as to define the quality of groundwater according to the classification of indexes. This method can simply and directly reflect which specific category or categories of factors in underground water are out of standard[8]. However, the influence mining area has on groundwater environment is a complex situation with multiple indexes and factors in mining. It is considered one-sided to evaluate the current situation of groundwater quality by a single index merely and it cannot reflect the overall situation of grounduwater quality. Thus, all-sided and comprehensive methods should be used to evaluate the groundwater quality, so as to obtain objective and overall evaluation results.

2.3 Bayesian Methods

The inductive reasoning theory proposed by British scholar Thomas l. b. bayes in on solving the problem of opportunity was later developed by some statisticians as a systematic statistical inference method, called bayesian method. In bayesian theory[9], parameters are regarded as random variables, which can effectively transform the prior probability into the posterior probability in the case of new information addition, so as to obtain the decision-making means of statistical results. The calculation formula of bayes is:

$$P(Bi \mid A) = \frac{P(B_i)P(A \mid B_i)}{\sum_{i=1}^{n} P(B_i)P(A \mid B_i)} \quad (1)$$

In this formula, P(Bi | A) is considered as posterior probability;

P(Bi) is considered as prior probability; P(A | Bi) is considered as likelihood probability. In the next step, we'll illustrate how P(Bi | A), P(Bi) and P(A | Bi) mean in the water quality evaluation.

The groundwater quality evaluation is to use the existing information and statistical methods to infer the possibility of water quality classification and take the maximum possibility as the result. When the bayesian formula is applied in the evaluation, A refers to water quality detection index, as xi; B refers to water quality classification, as yij with j refers to water quality classfication (j=1,2…, 5); i refers to detection index(i=1,2,…, n).

Thus, the bayesian evaluation model appliedi in groundwater quality evaluation can be represented as:

$$P(y_{ij} \mid x_i) = \frac{P(y_{ij})P(x_i \mid y_{ij})}{\sum_{i=1}^{5} P(y_{ij})P(P(x_i \mid y_{ij}))} \quad (2)$$

The formula can be applied in this project.

Evaluation steps:

Figure out P(yij) , the prior probability of water quality classification. Due to the lack of relevant statistical materials, it can be supposed that the probabilities of water quality classification are equal, that is, P(yij) =1/5(j=1, 2, 3, 4, 5).

(2)Figure out P(xi| yij), according to the geometric probability, the distance method is commonly used. We can do the calculation by the reciprocal of the absolute value of the distance between the actual measured value and the standard value.

Lij= | xi-yij | (j=1, 2, 3, 4, 5) refers to the distance between the actual detection value of the index i and the standard value and the higher the value is, the less likely it is that the water quality of a monitoring point belongs to Bi.

(3)Figure out P(yij| xi), which represents the probability that each water quality index belongs to each grade.

(4) Figure out the weight wi. The comprehensive evaluation of groundwater quality needs to take the influence different indexes have on water quality into account, and the entropy weight method is used

to give corresponding weights to each index. This method can offer objective results through simple calculation.

The steps of weight calculation are as follows:

Entropy is derived from the field of thermodynamics and represents the degree of systematic disorder [10]. The key steps of calculating the weight of each factor through entropy weight method in the water quality evaluation:

①Set m samples and n evaluation indexes to build the original matrix.

$$(X_{ij})_{m\times n} = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix}$$

②Then, to obtain the unitary matrix through data standalization process.

$$(Y_{ij})_{m\times n} = \begin{bmatrix} Y_{11} & \cdots & Y_{1n} \\ \vdots & & \vdots \\ Y_{m1} & \cdots & Y_{mn} \end{bmatrix}$$

When the detection value of evaluation factors has positive relations with their token attributes:

$$\frac{X_{ij} - \min(X_i)}{\max(X_i) - \min(X_i)} \quad (i = 1,2,\cdots,n)$$

When the detection value of evaluation factors has negative relations with their token attributes:

$$Y_{ij} = \frac{\min(X_i) - X_{ij}}{\max(X_i) - \min(X_i)} \quad (i = 1,2,\cdots,n)$$

③Figure out the comentropy of factors:

$$E_j = -\ln(m)^{-1}\sum_{i=1}^{m} T_{ij}\ln T_{ij} \quad (j = 1,2,\cdots,n)$$

$$T_{ij} = Y_{ij}/\sum_{i=1}^{m} Y_{ij}$$

Notes: If Tij=0 , then define $\lim_{T_{ij}} T_{ij}\ln T_{ij} = 0$

④Figure out the weight.

$$W_j = \frac{1 - E_j}{n - \sum_{j=1}^{n} E_j} \quad (j = 1,2,\cdots,n)$$

Obviously, $W_j \in [0,1]$ and $\sum W_j = 1$

(5) The solution of posterior probability Pi under multiple integrated indexes;

$$P_j = \sum_{i=1}^{n} w_i \cdot P(y_{ij} \mid x_i) \quad \textbf{(3)}$$

Pj is the posterior probability of 11 integrated indexes, that is, the probability that the water quality in mining area is at level j under the consideration of 11 integrated indexes.

(6) Final rating judgement. To decide the final level P=maxPj (j=1~5) considering the principle of maximum probability.

3. Results and discussion

With the same evaluation indexes, the single factor method and bayesian model were used to evaluate the water quality of mining study area. The evaluation results are shown in table 2. This study take the Groundwater quality standard (GB/T 14848-2017) as the evaluation standard. Due to the lack of Ⅴ class limit in the standards, the Ⅰ class water limit is taken as the Ⅰ class limit; the average value of Ⅰ class and Ⅱ class water limit is taken as the Ⅱ class limit and so on[11].

Table 2 statistics of two methods' results

	Bayesian model	single factor evaluation method										
		sulfate	COD_{mn}	ammomia nitrogen	nitrite	nitrate	fluoride	arsenic	nickel	total hardness	TDS	chloride
S01	I	II	I	II	II	I	I	I	I	II	II	I
S02	IV	II	V	IV	III	I	V	V	IV	V	IV	I
S03	II	III	I	I	I	I	IV	I	III	III	III	I
S04	V	V	I	III	II	I	I	I	III	V	IV	I
S05	V	V	I	III	II	I	I	I	III	V	IV	I
S06	II	III	I	III	II	I	I	I	III	III	III	I
S07	V	I	I	III	II	I	I	I	V	II	II	I
S08	I	I	II	II	II	I	I	I	I	I	I	I
S09	I	I	I	I	I	I	I	I	III	II	II	I
S10	II	I	I	III	I	I	I	I	III	II	II	I

The single factor method has the simpliest evaluation process without calculation. As long as we compare the actual dectetion value of water quality with the standard value, the level of water quality can be figured out, which can precisely reflect the specific overshoot situation and distribution of the pollution indexes. However, it cannot reflect the overall groundwater quality situation of the tailings pond.

When we use the bayesian model to evaluate the water quality, the effects those indexes have on water quality are taken into account. Besides, it can reduce the adverse effects outliers have on the results which cannot be affected by the indexes and samples' size. Thus, this method has stronger operability and applicability.

4. Conclusion

(1) We used the bayesian model to evaluate the groundwater quality in tailings pond of a mine in Southwest China. It shows that the water quality condition of samples S04, S05, S07, S02 isn't matched with the III class standard. Besides, the overall water quality of the mine area is moderate and the main factors of pollution are sulfate and nickel.

(2) It can be seen through the comparison of two different evaluation methods that the bayesian method has stronger integrity and more comprehensive consideration than the single factor method. Besides, this method can be applied to subjects with smaller sample with more convenient and faster calculation, which is worth popularization and application.

(3) With the enhancing of the environmental awareness in the mining area, the sustainable development of green mines is highly proposed in China. Thus, the evaluation system of the water quality in the mining area needs further improvement. Meanwhile, using the bayesian model flexibly can achive the aim of comprehensively, objectively and precisely evaluating the water quality in mining areas.

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References

[1] Liao Guoli, Lhuo Yinda, Wu Chao. Forecast models of heavy metal contamination near tailing dam and their application [J]. Science and Technology, 2004, 35 (6): 1009 — 1013.

[2] Tang Yu, Shuai Qin, Chai Xinna, Tang Zhiyong, Qiu Haiou. Investigation of Water Quality Assessment in Coal Mine [J].Environmental Science and Technology, 2014, 37 (S1): 390-396.

[3] Chatterjee R, Tarafder G, Paul S.Groundwater quality assessment of Dhanbad district, Jharkhand, India [J]. Bulletin of Engineering Geology and the Environment, 2010, 69(1): 137-141.

[4] Pan Jun, Gao Weichun, Zang Haiyang. Based on the fuzzycomprehensive appraisal in evaluation of surface water quality for Xiquan Lake [J]. Environmental Science & Technology, 2010, 33(S2): 551-553. (in Chinese)
[5] Zhang Xin, He Shilei, Zhang Yongzhao, et al. Study on grey relational analysis method for water quality assessment [J].Journal of Water Resources and Water Engineering,2010,21(5): 117-119. (in Chinese)
[6] Chen Peng, Wang Jiading, Yuan Liang, Xu Yuanjin, Si Dongdong. Application of Modified Nemerow Index and Fuzzy Comprehensive Evalution Method on Groundwater Quality Evaluation in Fenghuang Town [J]. Bulletin of Soil and Water Conservation, 2017, 37(02):165-170.
[7] Huang Weijun, Ding Jing. Hydrology and Water Resources System Bayesian Analysis about State-of-the-Art and Prospect[J].Advances In Water Science,1994(03):242-247.
[8] Zhang Xinyu, Xin Baodong, Liu Wenchen, Guo Gaoxuan, Lu haiyan, Ji Yiqun. Comparative analysis on three evaluation methods for groundwater quality assessment[J].Journal of Water Resources and Water Engineering,2011,22(03):113-118.
[9] Wang Zuoren, Yang Lin. Bayesian Inference and Main Progress [J].Statistics ang Information Forum, 2012, 27(12): 3-8.
[10] Xiao-Meng Wang, Kang Liu, Xu Qian. Entropy-weighted feature-fusion method for head-pose estimation [J]. EURASIP Journal on Image and Video Processing, 2016, 2016 (1).
[11] Wang Xinzhi, Zhang Huzi, Jia Zhen, Bao Yuzhuo, Jiang Weihong. Application of Single Index Method and Fuzzy Comprehensive Method in Water Quality Evaluation of Jilin City Section of Songhua River [J]. Environmental Science and Management, 2012, 37(09):184-187.