

The Antipollution Evaluation Of Phreatic Water By Comprehensive Index Evaluation Model Based On The Bayes

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Abstract: According to the defect of DRASTIC model in antipollution evaluation of phreatic water of Alluvial plain , selecting 8 assessment factors such as groundwater depth, gas zone lithology, aquifer sand layer thickness, aquifer hydraulic conductivity, rainfall supply, mining intensity, groundwater quality and comprehensive river coefficient, the comprehensive index evaluation model based on the bayes was built. The model was proposed to be applied to the evaluation of the antipollution of the phreatic water in Tian Town and surrounding areas in Weihe basin. The range number-possibility degree method is applied to calculate the weight of influence factors, then a phreatic water map of antipollution evaluation zone was suggested. The result shows that the calculation by vulnerability evaluation model based on the bayes is more conformed with the actual situations of study area, and the phreatic water map of antipollution performance evaluation zones can provide some important reference for making antipollution measures for the phreatic water of the study area.

1. Introduction

The evaluation of groundwater antipollution is a hot spot in the international hydrology work, and the results of the antipollution are the key to the feasibility of groundwater conservation measures. In 1987, the E.P.A. described the model of groundwater anti-pollution performance evaluation model, which is the most popular method in the world, but there are many flaws, so it can't be applied to the one and the other. According to literature 3 and 4, from the perspective of the urban antipollution assessment of phreatic water, although topography (T) also affects pollutant infiltration, the impact of topography factors can be ignored in the evaluation of urban antipollution assessment due to the small difference in topography among cities. The quota of each index in the evaluation of groundwater antipollution is discrete value, and different attribute values within the same level are given the same quota, so that the actual change of the index cannot be truly reflected on the antipollution of aquifer, thus affecting the objectivity of the final evaluation result [5-6]. DRASTIC model has shortcomings in the selection of indicators, quantification of indicators and weight determination of indicators in the evaluation of groundwater antipollution [7]. Combined with the hydrogeological structure, human activities and external natural factors of the study area, this paper, starting from the indicator factors influencing the phreatic antipollution, considers the quality, quantity of groundwater and the influence of human activities, and uses the principle and method of bayesian theory to build a comprehensive index evaluation model. The comprehensive analysis of the phreatic antipollution provides reasonable suggestions for the protection and rational utilization of groundwater.

2. The general situation of study area

The research area is located in the alluvial-diluvial plain in the eastern part of Guanzhong basin with a



wide and slow topography. The available water resources are extremely limited combined with the rapid regional development, large scale, the demand for water resources, and water became the bottleneck which restrict the development of the region. The area is rich in surface water, but the pollution is serious, the groundwater is the main supply for domestic water and irrigation water. The "three wastes" of industrial enterprises and the discharge of fertilizers and pesticides have caused serious pollution to the shallow groundwater in this area. Therefore, the security of water resources itself is very important. Only when the security of water itself is effectively guaranteed can the survival and development of the region be guaranteed. In order to protect and rationally utilize the groundwater resources of the area, the phreatic water antipollution shall be evaluated.

2.1 Hydrogeological condition

The study area is located in the eastern open area of Weihe basin, where the thick loose layer is deposited, which provides a good storage space for groundwater. According to the conditions of groundwater occurrence, it is mainly the pore water of quaternary loose rocks from 300 m to shallow groundwater. Groundwater types are composed of the fourth system quaternary alluvium pore phreatic, quaternary pore-phreatic in alluvial-diluvial deposits, the quaternary alluvial pore confined water and confined water in alluvial-diluvial deposits.

According to the hydrogeological profile of the study area, the first-order alluvial-diluvial fan zone is dominated by thin layer of fine sand and poor water abundance. The first-grade terraces and floodplain areas are mainly composed of sand and gravel, except that the surface layer of the floodplain over 8m is usually thin sand and silt interbedded. The first stage of the lower subgrade subsurface aquifer is slightly tilted to the south in the thick north and thin north. Its tip is at the back of the floodplain, and its front edge is nearly 30m lower than that of the floodplain. The distribution of the subsurface aquifer is relatively stable in the floodplain area, generally 2-6m thick. However, in the floodplain area near Jiaokou Town, the distribution of the subsurface aquifer is unstable, resulting in the connection between the phreatic aquifer and the shallow confined water. The modern diluvial fan is composed of sand and gravel layer, and the underlying aquifer is composed of silty clay or silty soil. Its distribution is relatively stable, with a general thickness of 4-6m and a partial thickness of 10m.

2.2 The groundwater quality status

According to the evaluation results in 2017, the phreatic water quality is inferior to III class water, and poor water quality accounts for 17% and it is mainly distributed on the north bank of Weihe River. The surface area distribution characteristics of water quality are obvious, and the water quality as a whole shows that the inorganic indexes such as iron ion, chloride, sulfate, nitrate, nitrite, dissolved solid, total hardness and potassium permanganate index exceed the standards. The content of heavy metals such as Cr^{6+} and Mn are higher than III class. From the evaluation results, it can be seen that the water quality of the whole area is poor because of the close relationship between the depth of underwater burial and the surface environment in the area, which is vulnerable to human activities and geochemical environment.

2.3 The status of groundwater exploitation

According to field investigation and water resources statistics, the total water supply was $9849 \times 10^4 \text{m}^3$ in the study area in 2014, the surface water supply was $5152 \times 10^4 \text{m}^3$, accounting for 52.3% of the total water supply, and the groundwater supply was $4673 \times 10^4 \text{m}^3$, accounting for about 47.4%. The large potential area of groundwater resources in the area accounts for 14.33% of the total area, and the medium potential area accounts for 29.18%, and the small area accounts for 4.70%, and the mining and replenishment balanced area accounts for 51.45%, and the over-exploited area accounts for 0.34%

2.4 The amount of groundwater resources

The total amount of the phreatic water natural supply resources in the study area is $14636.98 \times 10^4 \text{m}^3/\text{a}$, and the total amount of recoverable resources is $15557.85 \times 10^4 \text{m}^3/\text{a}$, of which the amount of freshwater

resources (salinity <1g/l) is 2060.89 x 104m³/a, accounting for 13.25%, and the amount of weak salt water is 79.17%. The natural replenishment resources of artesian water were 487.34 x 104m³/a, the recoverable resources were 366.81 x 104m³/a, and the fresh water resources were 26.27 x 104m³/a, accounting for 7.16%, and the weak salt water accounted for 89.50%.

3. The evaluation model of groundwater antipollution

The bayes comprehensive index model has four main assumptions in the evaluation of groundwater antipollution: Pollutants exist on the surface and in polluted rivers; Pollutant seepage through rainfall and from polluted river; Pollutants migrate with water; The optimal value of each index in the research area constitutes a standard evaluation unit.

3.1 The determination of the evaluation index of groundwater antipollution

When evaluating the phreatic antipollution in the study area, combined with the actual situation, the inherent attributes of the groundwater, human activities and external natural factors, and taking hydrogeological structure, surface water characteristics and pollution source distribution into account, the infiltration mechanism of pollutants from vertical and lateral direction was studied respectively. Groundwater depth, gas inclusion zone lithology, precipitation supply, water-bearing sand thickness, hydraulic conductivity coefficient of aquifer, exploitation intensity, groundwater quality and river comprehensive coefficient were selected as evaluation indexes of the phreatic antipollution. The integrated river coefficients include river water level, water quality and coastal lithology. The lower the river water level is, the better the water quality is, and the finer the lithologic particles along the river is, the smaller the impact on the coastal groundwater is, and the stronger the phreatic antipollution performance is.

There are n units to be evaluated in the work area, and each unit has m evaluation indexes. Let $X = (x_{ij})_{n \times m}$ $i = 1, 2, \dots, n, j = 1, 2, \dots, 8$ represent the characteristic value matrix of 8 indexes of n units in the work area. Then, the index element set of the evaluation of the phreatic antipollution of the i unit to be evaluated is $X_{ij} = (x_{i1}, x_{i2}, x_{i3}, x_{i4}, x_{i5}, x_{i6}, x_{i7}, x_{i8})$. Where $x_{i1}, x_{i2}, \dots, x_{i8}$ successively represents groundwater depth, gas inclusion zone lithology, precipitation supply, water-bearing sand thickness, water-carrying hydraulic conductivity coefficient of aquifer, exploitation intensity, groundwater quality and river comprehensive coefficient.

3.2 The standardization of indicators and determination of standard values

In order to eliminate the influence of different physical dimensions on the calculation results, the quantitative index characteristic values of each evaluation unit in the region are normalized. The three indexes of water-bearing sand thickness, groundwater quality and groundwater depth are positive indexes, that is, the antipollution of the evaluation unit increases with the increase of the index value, and the normalization is carried out according to the principle of that the smaller is better. The four indexes including lithology, precipitation supply, hydraulic conductivity coefficient of aquifer, exploitation intensity and river comprehensive coefficient are the reverse indexes, that is, the antipollution of the evaluation unit decreases with the increase of index value, and the normalization is carried out according to the principle of that the bigger is better. The standardized value matrix of the index is finally obtained, where the normalization formula of the index is as follows:

$$\text{Incremental type (the smaller is the better): } r_{ij} = \frac{\max_j x_{ij} - x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} \quad (1)$$

$$\text{Decline type (the bigger is the better): } r_{ij} = \frac{x_{ij} - \min_j x_{ij}}{\max_j x_{ij} - \min_j x_{ij}} \quad (2)$$

Where: r_{ij} represents the standardized value of indicator j of evaluation unit i ; $\max_j x_{ij}$ represents the maximum eigenvalue of indicator i in the whole. $\min_j x_{ij}$ represents the minimum eigenvalue of indicator i in the whole.

Based on the influence of indexes on antipollution and the safety of evaluation, the index standard value of the standard evaluation unit in the evaluation area is determined:

$$\begin{cases} r_{01} = \min(r_{i1}), i = 1, 2, \dots, n \\ r_{02} = \min(r_{i2}), i = 1, 2, \dots, n \\ \dots, \dots, \dots \\ r_{011} = \min(r_{i11}), i = 1, 2, \dots, n \end{cases} \quad (3)$$

3.3 The determination of index weight

The weight is determined by the possibility degree method proposed by Wang Shuying based on the level difference of 11 tone operators and the value of relative membership [8-9]. The interval number algorithm is used to calculate the attribute value of each index, the probability matrix of pairwise comparison is constructed, and the corresponding weight vector is obtained by using the weight formula, and then the samples are sorted and selected. The correspondence between tone operator and quantitative scale is shown in table 1.

Table 1. The relationship between tone operator and relative importance degree

Tone operator	same	little	slight	quite	clear
The quantitative scale	0.5	[0.5, 0.55]	[0.55, 0.60]	[0.60, 0.65]	[0.65, 0.70]
prominent	complete	extraordinary	extreme	extremer	unparalleled
[0.70, 0.75]	[0.75, 0.80]	[0.80, 0.85]	[0.85, 0.90]	[0.90, 0.95]	[0.95, 1.0]

3.4 The establishment of evaluation model of the phreatic antipollution

Set B_i as the probability event that the feature index of the standard evaluation unit $r_0(k)$ is similar to the feature index of the unit to be evaluated $r_i(k)$ ($i = 1, 2, \dots, m; k = 1, 2, \dots, n$). That is, the randomness and uncertainty of the evaluation of antipollution of the unit to be evaluated can be expressed by conditional probability $P(B_i / r_0(k))$, and its expression is as follows:

$$P(B_i / r_0(k)) = \frac{P(B_i r_0(k))}{P(r_0(k))} = \frac{P(B_i) P(r_0(k) / B_i)}{\sum_{i=1}^m P(B_i) P(r_0(k) / B_i)} \quad (4)$$

However, in the practical application of bayes, the prior probability $P(B_i)$ is often difficult to be determined accurately in advance. In the evaluation of anti-pollution, we generally believe that the probability of similarity between the feature index value of the unit to be evaluated and the feature index value of the standard evaluation unit is equally possible, that is to say, prior probability is $P(B_i) = 1/n$. Therefore, the equation (4) can be changed into:

$$P(B_i / r_0(k)) = \frac{P(B_i r_0(k))}{P(r_0(k))} = \frac{P(r_0(k) / B_i)}{\sum_{i=1}^m P(r_0(k) / B_i)} \quad (5)$$

The similar probability of the characteristic value of a single index between the standard evaluation unit and the unit to be evaluated can be calculated according to equation (6). The specific calculation steps are as follows:

Calculate the similar probabilities P_{ik} of the same index between the standard evaluation unit and the evaluation unit. Let $L_{ki} = |r_0(k) - r_i(k)|$, where L_{ki} represents the distance between an index feature of the standard evaluation unit and its corresponding index feature value of the unit to be evaluated.

Taking L_{ki} to be normalized, and it's a formula:

$$d_{ik} = \frac{L_{ik}}{\sum_{i=1}^k L_{ik}} = \frac{|r_0(k) - r_i(k)|}{\sum_{i=1}^m |r_0(k) - r_i(k)|} \quad (i = 1, 2, \dots, m; k = 1, 2, \dots, n) \quad (6)$$

According to the characteristics of geometric probability, assuming that P_{ik} is inversely proportional to distance L_{ki} , we can get:

$$P_{ik} = \frac{1/d_{ik}}{\sum_{i=1}^m 1/d_{ik}} \quad (i = 1, 2, \dots, m; k = 1, 2, \dots, n) \quad (7)$$

We calculate the weighted probability that the index features of the standard evaluation unit are similar to those of the unit to be evaluated. The formula of P_i is as follows:

$$P_i = \sum_{k=1}^n W_k P_{ik} \quad (i = 1, 2, \dots, n) \quad (8)$$

4. The assessment of the phreatic antipollution in the study area

The weighted probability P_i of each evaluation unit and the standard evaluation unit in the evaluation area is calculated according to the bayes weighted evaluation model of the phreatic antipollution. The contour map of P_i is automatically generated by MapGis software, and the phreatic antipollution is divided according to the actual situation of the study area.

4.1 The subdivision of unit and standardization of evaluation indexes

With the help of MapGis technology and combined with township boundaries, hydrogeological units and geological boundaries, the study area was divided into 420 units with an area of about 420km², and each unit was an independent evaluation unit.

Each evaluation unit contains 8 evaluation indexes, including groundwater depth, gas inclusion zone lithology, precipitation supply, water-bearing sand thickness, water-bearing hydraulic conductivity coefficient of aquifer, exploitation intensity, groundwater quality and river comprehensive coefficient. Then, the matrices of 8 evaluation indexes of 420 evaluation units in the study area were respectively $X = (x_{ij})_{420 \times 8}$, $i = 1, 2, \dots, 420$, $j = 1, 2, \dots, 8$. The evaluation indexes are normalized according to equations (1) and (2), and the index eigenvalue matrix $R = (r_{ij})_{n \times 8}$, $i = 1, 2, \dots, n$, $j = 1, 2, \dots, 8$ and the standard index eigenvalue $r_0(k)$ ($k = 1, 2, \dots, n$) are obtained.

$$r_0(k) = [0, 0, 0, 0, 0, 0, 0, 0]$$

$$R = (r_{ij})_{420 \times 8} = \begin{bmatrix} 1.00 \cdots 0.45 \cdots 0.01 \\ 0.75 \cdots 0.25 \cdots 0.00 \\ 1.00 \cdots 0.88 \cdots 0.88 \\ 1.00 \cdots 1.00 \cdots 1.00 \\ 1.00 \cdots 1.00 \cdots 0.97 \\ 1.00 \cdots 0.38 \cdots 0.88 \\ 1.00 \cdots 0.45 \cdots 0.01 \\ 1.00 \cdots 0.50 \cdots 1.00 \end{bmatrix}$$

4.2 The determination of index weight in the study area

According to the method of equipossibility, a total of 8 evaluation indexes including groundwater depth, gas inclusion zone lithology, precipitation supply, water-bearing sand thickness, water-bearing water conductivity coefficient, exploitation intensity, groundwater quality and river comprehensive coefficient were weighted, and the weight calculation results were shown in table 2.

Table 2. Weight distribution of each evaluation factor

evaluation indexs	groundwater depth	gas inclusion zone lithology	precipitation supply	water-bearing			groundwater quality	river comprehensive coefficient
				water-bearing sand thickness	water conductivity coefficient	exploitation intensity		
weight	0.219	0.296	0.172	0.058	0.015	0.049	0.059	0.132

4.3 The calculation of similar weighted probability in study area

The standardized matrix of 420 evaluation units and 8 indicators in the study area is $R = (r_{ij})_{420 \times 8}$, $i = 1, 2, \dots, 420$, $j = 1, 2, \dots, 8$. The similar weighted probability between the unit to be evaluated and the standard evaluation unit is calculated according to equation (8), and the weighted probability of the phreatic antipollution of each evaluation unit is calculated according to the integrated index model based on the bayes.

$$P = (p_{ij})_{420 \times 8} = \begin{bmatrix} 0.818 \cdots 0.462 \cdots 0.225 \\ \cdot \quad \cdots \quad \cdots \quad \cdot \\ \cdot \quad \cdots \quad \cdots \quad \cdot \\ 0.705 \cdots 0.308 \cdots 0.229 \\ \cdot \quad \cdots \quad \cdots \quad \cdot \\ \cdot \quad \cdots \quad \cdots \quad \cdot \\ 0.251 \cdots 0.762 \cdots 0.648 \end{bmatrix}$$

4.4 The evaluation results

The weighted probability P_j of each evaluation unit in the evaluation area is calculated according to the evaluation model of the phreatic antipollution, and the contour map of P_j is automatically generated by MapGis software. Then, according to the actual situation of the evaluation unit in the study area, the

contour line is modified so as to make the evaluation result more consistent with the actual situation of the work area. Finally, the phreatic antipollution of the study area was divided according to the comprehensive evaluation criteria (figure 1). Zoning standards are as follows:

weak antipollution area : $P_j \geq 0.80$; general antipollution area: $0.60 \leq P_i < 0.80$

medium antipollution area: $0.40 \leq P_i < 0.60$; strong antipollution area: $0.10 \leq P_i < 0.40$

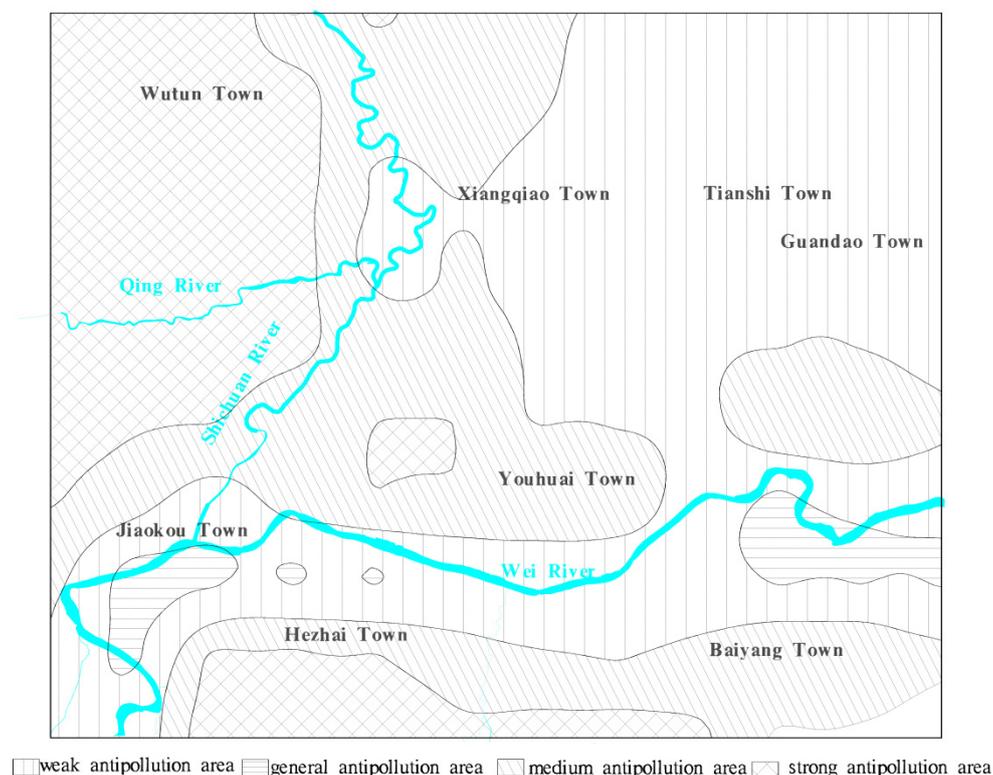


Figure 1. The zoning map for phreatic antipollution properties of the research area

The study area is mainly distributed in the diluvial fan to the north of Weihe River and west of Shichuan River, and the modern diluvial fan in Lintong area. These areas have a small amount of rainfall infiltration and a large depth of water level. The lithology below the water level is dominated by silty clay with a small permeability coefficient. The lithology of the gas inclusion zone is dominated by silty clay and silty soil. All of the above factors will have a greater blocking effect on pollutants, and the migration and diffusion rate of pollutants is small, and groundwater is more difficult to be polluted.

The general phreatic antipollution area mainly distributed in the northern bank of Weihe River floodplain and first class terrace near Guandao Town. In this region, the water aquifer and the gas inclusion zone media have larger sand content and particle size, stronger permeability and weak adsorption and degradation ability of pollutants. The water level is low near the floodplain of Shichuan River, Qinghe River and the northern bank of Weihe River. The surface soil is mainly sandy and gravel with a large amount of replenishment, which is conducive to the infiltration of pollutants. However, the permeability coefficient of the aquifer is less than that of the more vulnerable zones, and the lithology of the high flood beaches in the northern shore of Weihe River is dominated by silty clay, silty soil and silty sand.

The weak phreatic antipollution area is mainly distributed near Jiaokou Town and Shuangwang Town in nutrient-laden flood land, where the phreatic depth in the area is small, and the aquifer permeability is good, and it mainly accepts IV class water quality of Weihe River supplies.

5. Conclusions and recommendations

(1) Using the bayes theory, considering the geological environment condition factors, human activities and natural factors, starting from the influence factors of the phreatic antipollution, we build a comprehensive evaluation model of the phreatic antipollution. The application example verifies the feasibility and rationality of the model.

(2) Considering the fuzziness of the importance of the evaluation indexes of the phreatic antipollution, the equal possibility method is adopted to determine the weight of the indexes, so that the distribution of the weight of the evaluation index is more reasonable, which overcomes the deficiency of the weight of the traditional evaluation index.

(3) The comprehensive index evaluation model of the phreatic antipollution based on bayes is established on the basis of in-depth analysis of local hydrogeological conditions, which has a certain limitation. In addition, the model has a larger subjectivity in the phreatic antipollution, and we should strengthen the research in this field.

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