Application of DRASTIC Entropy Weight Model Method in Groundwater Vulnerability Evaluation in Ordos Area

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Abstract. The northeastern part of the Ordos Basin is the main recharge area of regional groundwater. The groundwater resources are relatively scarce. The main water supply source in the area is shallow groundwater, and there are many industrial and mining enterprises in the district. The potential groundwater pollution risk is high, and the shallow groundwater vulnerability evaluation in the region is of great significance for groundwater resources protection. The weight of each indicator of the traditional DRASTIC model is fixed and does not change with the regional conditions, which may cause deviations in the evaluation results. This time, based on the DRASTIC model, the entropy weight coefficient method is introduced to determine the index weight, and the DRASTIC entropy weight model is established to obtain a more scientific and close to the actual conditions of the study area, and provide an important reference and basis for the protection of regional groundwater resources.

1. Introduction
The Ordos area is rich in mineral resources, containing various minerals such as oil, gas, coal, and uranium[1, 2]. It is an important energy and chemical base in China, the demand for water resources is large, moreover, it is located in arid and semi-arid area, with a fragile ecological environment, less rainfall and more evaporation, the water resources are of great significance to ecological protection. The water supply in the area is mainly groundwater. In recent years, urbanization has accelerated and mining activities have been frequent. Human activities are likely to cause groundwater pollution. The evaluation of regional groundwater vulnerability evaluation is of great significance to groundwater pollution prevention.

Research works related to groundwater vulnerability evaluation have been extensively carried out both in China and abroad, and put forward a variety of evaluation methods such as: overlapping index method, statistical method, process mathematical simulation method and fuzzy mathematical method[3-5]. Among them, the stack index method is the most widely used, and this method is
relatively simple and has strong operability[5]. The evaluation models in the overlay index method has DRASTIC, GOD and EPIK, etc[5]. The DRASTIC model was proposed by the U.S. Environmental Protection Agency in 1987 and has been widely used in groundwater vulnerability evaluation research in China and abroad[6]. The DRASTIC model gives each indicator a fixed weight, and divides each indicator into different levels [7] to reflect the influence of different indicators on the vulnerability of aquifers.

The weight of each indicator of the traditional DRASTIC model is fixed and does not change with the regional conditions[8]. Taking into account the different physical and hydrogeological conditions in different regions, the traditional DRASTIC model is not very adaptable, which may cause deviations in the evaluation results. In order to obtain scientific and reasonable shallow groundwater vulnerability evaluation results, this time based on the DRASTIC model, the entropy weight coefficient method was introduced to determine the index weight, and the DRASTIC entropy weight model was established. The smaller the entropy of a certain index, the greater the degree of variation of the index value, the more information provided, the greater the weight ratio [9].

The study area is the northeastern part of the Ordos Basin. The regional watershed runs through the area, which is the main recharge area of regional groundwater, the groundwater resources are relatively scarce. The main water supply source in the area is shallow groundwater. Moreover, there are many residential areas and industrial and mining enterprises in the district, and the potential risk of groundwater pollution is high. The conditions of the study area are typical, and the shallow groundwater vulnerability evaluation in the area has important significance for groundwater protection in research areas. It can guide the development and protection of groundwater resources in arid and semi-arid areas of the Ordos Basin.

2. DRASTIC entropy weight model

This time, based on the DRASTIC model, the entropy weight coefficient method was introduced to determine the index weight, and the DRASTIC entropy weight model was established to evaluate the groundwater vulnerability. The model refers to the "Technical Requirements for Groundwater Vulnerability Evaluation"[10] to select seven indexes of groundwater depth (D), net aquifer recharge (R), aquifer medium (A), soil medium (S), topographic slope (T), vadose zone, lithology (I) and permeability coefficient (C) as evaluation factors of groundwater vulnerability evaluation.

2.1. Definition of entropy

The concept of entropy was first proposed by the German physicist Clausius in 1865. It originated from physical thermodynamics, was first used in the field of physics, and later introduced into information theory. Entropy is a way to measure the uncertainty of the system state, when the system is in different states in n and the probability of each state is $p_i (i=1,2,3...n)$, the entropy of the system is $E = -\sum_{i=1}^{n} p_i \ln p_i$.

In the formula, $0 \leq P \leq 1; \sum_{i=1}^{n} p_i = 1$, when $p_i = 1/n (i=1,2,..,n)$, the probability of each state is equal, the entropy takes the maximum value: $E_{max} = \ln (n)$. That is, the smaller the entropy of a certain state, the greater the degree of variation of the state, and the greater the weight in the comprehensive evaluation. In the specific evaluation work, the weight of each indicator can be calculated by using entropy according to the degree of variation of each indicator value. All indicators are weighted to obtain a more objective comprehensive evaluation result.

2.2. DRASTIC entropy weight evaluation model

Entropy method is based on the concept and character of entropy, judge by quantifying multi-objective information and the experience of decision makers, an objective method to provide data support for multi-objective decision-making. Introduce it into the groundwater vulnerability evaluation, and establish an entropy weight evaluation model based on DRASTIC. The steps are as follows:
Step 1: There are n samples to be evaluated, and each sample has m evaluation indexes, then construct the evaluation index eigenvalue matrix based on the measured original data: 
\[ X = \left( x_{ij} \right)_{m \times n}, (i=1,2,3,...m, j=1,2,3,...n). \]

Step 2: According to the character of different evaluation indicators (The larger the value, the lower the score, and the lower the comprehensive index of groundwater vulnerability, including D and T indicators; the smaller the value, the lower the score, including R, A, S, I, C indicators). After grading each evaluation index, the eigenvalue matrix of the evaluation index quota is obtained as follows:
\[ X' = \left( x'_{ij} \right)_{m \times n}. \]

Step 3: Calculate the i-th evaluation index condition, the proportion of the characteristic value of the j-th evaluation sample in all i indicators:
\[ p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}. \]

Step 4: Calculate the entropy of the i-th evaluation index:
\[ e_i = \frac{1}{mn} \sum_{j=1}^{n} p_{ij} \ln p_{ij}. \]

Step 5: Calculate the weight of the i-th evaluation index:
\[ a_i = \frac{(1-e_i)}{\sum_{i=1}^{m} (1-e_i)}. \]

Step 6: Calculate the comprehensive evaluation value of each sample:
\[ W_j = \sum_{i=1}^{m} a_i p_{ij}. \]

Step 7: Sort each sample according to the pros and cons of Wj from large to small.

2.3. Evaluation parameter weight

According to the score and weight of each single index evaluation factor (Table 1), the groundwater vulnerability index is calculated. The maximum value of groundwater vulnerability index calculated by the traditional DRASTIC model is 230 and the minimum value is 23. The maximum value calculated this time is 202 and the minimum value is 23. The maximum value of groundwater vulnerability evaluation index calculated by DRASTIC entropy weight model is 10, and the minimum value is 1. The maximum and minimum values calculated this time are 9 and 1. The larger the comprehensive index, the lower the anti-pollution performance, and the more easily the groundwater will be polluted. Conversely, the smaller the comprehensive index, the higher the anti-fouling performance, and the less likely the groundwater will be polluted.

Table 1. Traditional DRASTIC and entropy weight DRASTIC factor weight table.

| Evaluation factor          | Traditional weight | Entropy weight model calculation weight |
|----------------------------|--------------------|----------------------------------------|
| Depth to groundwater level (D) | 5                  | 0.1432                                 |
| Net aquifer recharge (R)    | 4                  | 0.1431                                 |
| Aquifer medium (A)          | 3                  | 0.1427                                 |
| Soil medium (S)             | 2                  | 0.1430                                 |
| Topographic slope (T)       | 1                  | 0.1429                                 |
| Unsaturated zone lithology (I) | 5              | 0.1427                                 |
| Hydraulic conductivity (C)  | 3                  | 0.1425                                 |

3. The groundwater vulnerability evaluation

The data sources of the above seven types of indicators are as follows:

Depth to groundwater level (D): Select the actual data of the buried depth of shallow groundwater in the study area from May to June 2017;

Soil medium (S): Obtained based on the survey data of the surface soil lithology survey;

Net aquifer recharge (R): the precipitation infiltration coefficient of the study area is reference to the empirical values of different lithologies[11]. The multi-year average precipitation and the
precipitation infiltration coefficient of the study area are superimposed and calculated to obtain the distribution of net aquifer recharge of the study area;

Topographic slope (T): Obtained from remote sensing DEM data in the study area;

 Unsaturated zone lithology (I): The thickness of the Quaternary strata in the northeastern part of the Ordos Basin is generally thin. Most thickness of the stratum is less than 2 meters, and the lithology of the unsaturated zone is mainly determined based on the regional hydrogeological map and actual survey data.

Hydraulic conductivity (C): The lithology of shallow groundwater aquifer is determined according to the regional hydrogeological map, and the permeability coefficient of the aquifer is reference to empirical values[10].

The evaluation index score range of this groundwater vulnerability evaluation is 1-10, corresponding to the scope and classification of each evaluation index, refer to the technical requirements for groundwater vulnerability evaluation (GWI-D3) (China Geological Survey)[11]. The specific index range and score are shown in Table 2.

### Table 2. The improved DRASTIC model index scoring system (R:Range, S:Score)

| Groundwater depth (m) | Net aquifer recharge (mm) | Aquifer medium (A) | Soil medium | Topographic slope (%) | Unsaturated zone lithology | Hydraulic conductivity (m/d) |
|-----------------------|--------------------------|------------------|-------------|----------------------|---------------------------|-----------------------------|
| R S R S R S R S R S | R S R S R S R S R S | R S R S R S R S | R S R S R S R S | R S R S R S R S R S | R S R S R S R S R S | R S R S R S R S R S |
| 0-1.5 | 10 | 0-51 | 1 | Clay | 1 | Non-swelling and non-cohesive clay | 1 | 0-2 | 10 | Clay | 1 | 0-4.1 | 1 |
| 1.5-4.6 | 9 | 51-71.4 | 2 | Loam | 2 | Rubblish | 2 | 2-4 | 9 | Loam | 2 | 4.1-12.2 | 2 |
| 4.6-6.8 | 8 | 71.4-91.8 | 3 | Sandy loam | 3 | Clayey loam | 3 | 4-7 | 8 | Sandy loam | 3 | 12.2-20.3 | 3 |
| 6.8-9.1 | 7 | 91.8-117.2 | 4 | Silt | 4 | Silty loam | 4 | 7-9 | 7 | Silt | 4 | 20.3-28.5 | 4 |
| 9.1-12.1 | 6 | 117.2-147.6 | 5 | silty-fine sand | 5 | loam | 5 | 9-11 | 6 | silty-fine sand | 5 | 28.5-34.6 | 5 |
| 12.1-15.2 | 5 | 147.6-178 | 6 | Fine sand | 6 | Gravelly loam | 6 | 11-13 | 5 | Fine sand | 6 | 34.6-40.7 | 6 |
| 15.2-22.9 | 4 | 178-216 | 7 | medium sand | 7 | Swelling or agglomerating clay | 7 | 13-15 | 4 | medium sand | 7 | 40.7-61.1 | 7 |
| 22.9-26.7 | 3 | 216-235 | 8 | Coarse sand | 8 | peat | 8 | 15-17 | 3 | Coarse sand | 8 | 61.1-71.5 | 8 |
| 26.7-30.5 | 2 | 235-254 | 9 | Gravel | 9 | Gravel (sand layer) | 9 | 17-18 | 2 | Gravel | 9 | 71.5-81.5 | 9 |
| >30.5 | 1 | >254 | 10 | Pebble | 10 | Pebble (Gravel Layer) | 10 | >18 | 1 | Pebble | 10 | >81.5 | 10 |

### 4. Evaluation results

#### 4.1. Comparative analysis of results of DRASTIC model and DRASTIC entropy weight model

According to the "Regional Groundwater Pollution Investigation and Evaluation Specifications (DZ/T0288-2015)", the groundwater system vulnerability zone in the study area is divided into 5 levels according to the comprehensive index: high vulnerability zone, medium to high vulnerability zone, medium vulnerability zone, medium to low vulnerability zone, low vulnerability zone. The shallow groundwater vulnerability zone partition calculated by DRASTIC model and DRASTIC entropy weight model are shown in Figure 1, Figure 2 and Table 3.

In the evaluation results, the area of the evaluation zone of the DRASTIC model is ranked as follows: High and medium vulnerability zone > Medium vulnerability zone > Low and medium vulnerability zone > High vulnerability zone > Low vulnerability zone. The area of the evaluation zone of the DRASTIC entropy weight model is ranked as follows: High and medium vulnerability zone > Low and medium vulnerability zone > Medium vulnerability zone > High vulnerability zone > Low vulnerability zone. The DRASTIC entropy weight model for areas with high vulnerability and medium...
to high vulnerability is larger than the DRASTIC model, the area of other partitions is smaller than the latter.

Table 3. Groundwater vulnerability zone

| DRASTIC Composite index | DRASTIC entropy weight model | Partition type |
|-------------------------|------------------------------|---------------|
| [23-64]                 | [1-2]                        | low vulnerability zone |
| (64-105]                | (2-4]                        | medium to low vulnerability zone |
| (105-146]               | (4-6]                        | medium vulnerability zone |
| (146-187]               | (6-8]                        | medium to high vulnerability zone |
| (187-230]               | (8-10]                       | high vulnerability zone |

The difference between the evaluation results of the traditional DRASTIC model and the DRASTIC entropy weight model is mainly reflected in branch-shaped valleys and areas where aeolian sand is distributed. The main reason for the difference is that the DRASTIC entropy weight model is an evaluation index weight calculated based on the actual situation of the study area. It is more in line with the actual geological and hydrogeological conditions of the study area, and the weight of the DRASTIC evaluation index is fixed and does not change with the study conditions.

4.2. The shallow groundwater vulnerability assessment results of DRASTIC entropy weight model

The high vulnerability zone of shallow groundwater is mainly distributed in river valleys, and its surface lithology is alluvial deposits, medium-coarse sand with pebbles, etc. These zones have good infiltration conditions, more active exchange of surface water and groundwater, so the shallow groundwater is easily to be polluted. The medium to high vulnerability zones have the widest distribution, mainly in the northern part of the study area and the southern bedrock platform. The thickness of the quaternary strata in the region is generally small, the infiltration conditions are relatively good, and the permeability coefficient of shallow aquifers is large. The medium vulnerability zone is mainly distributed in the southeast of the study area. The lithology of the aeration zone and aquifer is composit ed by Quaternary aeolian sand and underlying sandstone. The low vulnerability and middle to low-vulnerability areas are mainly located in the hilly and mountainous area in the east of the study area, where erosion gullies are developed, and the terrain slope is relatively large, conducive to surface water runoff. In this area the regional water level is buried deep, and shallow groundwater is hard to be polluted.
5. Conclusion

(1) In the traditional DRASTIC model, the index weights are fixed, while the DRASTIC entropy weight model introduces the entropy weight coefficient method to determine the index weight, which can better reflect the influence of regional hydrogeological conditions and soil structure on the anti-pollution properties of groundwater.

(2) The high vulnerability zone of shallow groundwater are mainly distributed in river valleys, which are distributed in strips. Shallow groundwater is the main sources of water supply in the Ordos area, so it is important to strengthen the treatment of domestic sewage and pollution sources around the river. The mid-to-high vulnerability zones are the most widely distributed, and the pollution control of industrial and mining enterprises should be strengthened to prevent the pollution of shallow groundwater in the area.

(3) This work took the northeastern part of the Ordos Basin as the study area to carry out shallow groundwater vulnerability assessment, and the results reflected the potential risk of regional groundwater pollution, it meets the regional conditions and has regional representativeness. This research has important significance and promotion value for guiding the development and protection of groundwater resources in arid and semi-arid areas of the Ordos Basin.

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