Study on Zoning Effect of Shallow Geothermal Energy Suitability Based on Structural Matrix Method

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Abstract

Geothermal energy is a clean, renewable resource that can be harnessed to help China achieve its twofold carbon goal and advance its energy security policy. Shallow geothermal, middle-deep geothermal, and dry hot rock geothermal all belong to the clean energy. The thermal energy held in rock, soil, groundwater, and surface water up to a depth of 200 metres is referred to as the shallow geothermal variety, which is characterized by temperatures below 25°C. Its use is mostly dependent on ground source heat pump technology. The ground source heat pump ground pipe heat exchange system, the ground source heat pump groundwater heat exchange system, and the ground source heat pump surface water heat exchange system are all included in the shallow geothermal heat exchange mechanism. The structural matrix approach is used in this study to determine if the groundwater heat exchange system for the shallow geothermal ground source heat pump in Sanmenxia's urban setting is appropriate. The results showed that: the most

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influential factor was hydrogeological conditions, followed by hydrodynamic and water chemistry conditions. Aquifer recharge capacity and water capacity was the necessary condition of suitability partition. Studied hydrodynamic field and chemical field, analyzed aquifer thickness and groundwater flow under current conditions and determined the appropriate zoning, proposed groundwater aquifers and recharge horizon.

Keywords: Energy, structural matrix method, shallow, geothermal energy, suitability.

Geothermal energy's importance as a renewable and environmentally benign energy source becomes more and more important as worldwide concerns over the energy and environmental crises grow. Utilizing and putting geothermal energy to use is very important, especially in light of China's dual carbon aims and energy security strategy [1, 2]. Geothermal energy primarily refers to thermal energy contained in rock, soil, groundwater, and surface water up to a depth of 200 metres and temperatures under 25°C. It is divided into three categories: shallow geothermal, hydrothermal geothermal, and dry hot rock geothermal. Ground source heat pumps' heat exchange technology is typically used to harness this energy [3, 4]. Ground pipe, groundwater, and surface water heat exchange systems are among the various shallow geothermal energy heat exchange systems. They are all powered by ground source heat pumps. The structural matrix method tackles complicated decision-making challenges as a powerful tool for qualitative and quantitative analysis [5, 6]. In order to determine the suitability of the groundwater heat transfer system for shallow geothermal ground source heat pumps in the urban area of Sanmenxia, this study employs the structural matrix approach. The contents are as follows.

1 Occurrence Conditions of Shallow Geothermal Energy

1.1 Geography and Geological Background

Sanmenxia is located in the west of Henan Province. It is the economic and cultural center in the border area of Henan. The west is adjacent to Tongguan, Shanxi. In the south, it borders Xiaoqinling, Weishan and Lushi County; in the east, it borders Luoning County [7, 8]. It located to the north of the Yellow River, Ruicheng and Pinglu in Shanxi Province across the Yellow

River, and the traffic is very convenient. The scope of the study area is the entire urban area of Sanmenxia, with an area of about 117.54 km^2. Sanmenxia is a new industrial city mainly engaged in electric power, textile, machinery manufacturing, metallurgy and chemical industry [9]. It's changing with each passing day.

The geography of the study area has a higher height in the south-east and a declining slope to the north-west. Maximum elevation in the area is 640 m, minimum elevation is 308 m, resulting in a 332 m relative height difference. Loess and river landforms are the two main divisions of Sanmenxia's geomorphology [10, 11].

The study region primarily consists of Cenozoic strata, of which the Quaternary Holocene is about 30 m thick and the Pleistocene is 370–650 m thick. From the perspective of tectonic units, Sanmenxia City is located in the north of the Huaxiongtai Margin Depression (Second-level) of the China-North Korea Quasi-Platform (First-level) [12, 13]. There are mainly north-east, east-west and north-west faults. The study area belongs to the Yellow River Basin and is mainly composed of the Yellow River and its tributaries – Qinglongjian River and Canglongjian River. The research area is located in a warm temperate semi-arid continental monsoon climate zone and is predominantly composed of Cenozoic strata. The four seasons are distinct, and the inter-annual and intra-annual changes in meteorological elements such as precipitation, evaporation, and temperature are obvious. The landform of the study area is depicted in Figure 1.

1.2 Hydrogeological Conditions

The predominant groundwater type in the study region comprises loosely structured pore water, most prevalent in the valley terrace zones of the Yellow River and its tributaries. Its sand layer is characterized by a typical "binary structure" of upper fine and lower coarse and a "multiple structure" of coarse and fine layers. Due to the thickness of the aquifer, the distribution law of burial and the particle size, the water richness varies. See Figure 2. for lithology composition of aquifer in water rich area.

Using the water output of a single well at a drawdown of 10 m as the basis for water-rich zoning, Five categories – highly water-rich, water-rich, moderately water-rich, low water-rich, and water-poor – can be used to categorize the region according to its water availability.

I. Strong water-rich area (single well water inflow >3500 m^3/d): primarily occupy the floodplain of the Yellow River, and the first-level terraces to

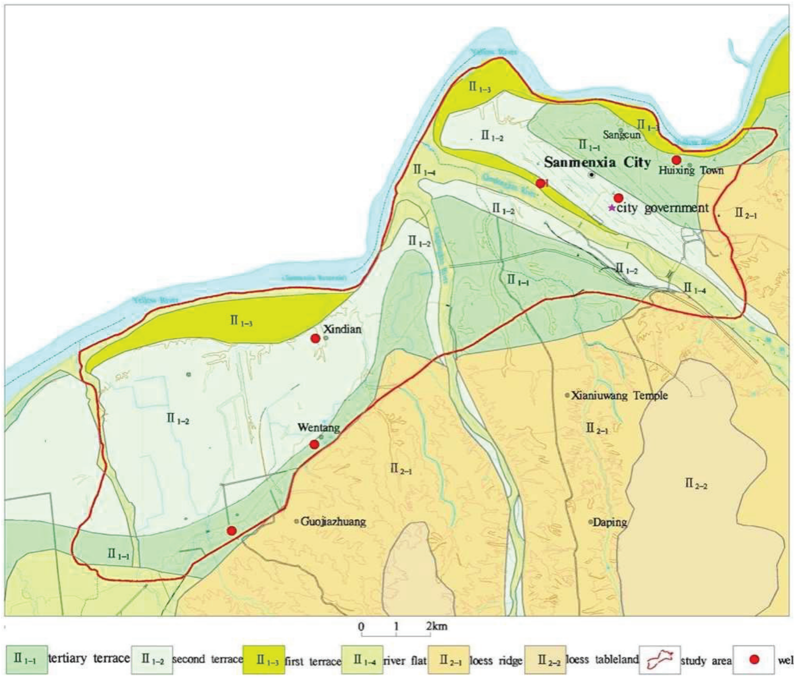

Figure 1 Landform map of the research area.

the south of Sanmenxia Reservoir. The permeability coefficient is large, and it is a strong water-rich area [14].

II. Water-rich area (single well water inflow 2000–3500 m^3/d): primarily populate the second terrace south of the Yellow River of the Sanmenxia Reservoir and the valley and terrace of the Canglongjian River in the Qinglongjian River. It is composed of sand and fine sand and is a water-rich area.

III. Medium water-rich area (Single well water inflow 1000$\sim$2000 m^3/d): primarily populate the Qinglongjian River valley terraces and the secondary trailing edge and tertiary terraces of the Yellow River in Sanmenxia. Sands, particularly medium-fine and fine sands, make up the majority of the aquifer lithology in these zones. The third terrace of the Yellow River to the north of Yellow River Road and the loess beam south of the municipal paper mill make up the majority of the low water-rich sector.

IV. Weak water-rich area (identified by a single well water inflow of 500–1000 m^3/d): primarily situated north of the Yellow River Road, on

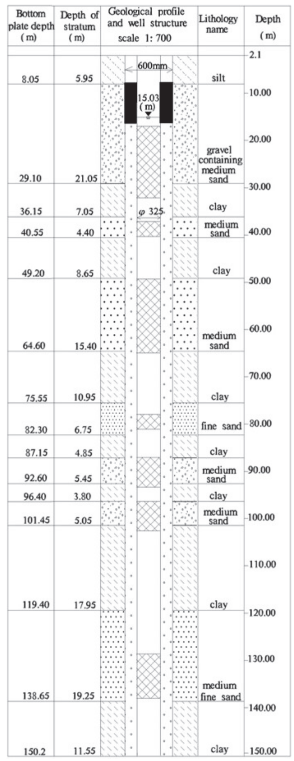

Figure 2 Geological column diagram.

the third-order terrace of the Yellow River, and south of the municipal paper mill, on the loess beam.

V. The Sanmenxia Railway Station is the major location of water-poor areas, which are indicated by a single well water inflow of less than 500 m^3/d. In this area, silt and clay make up the majority of the aquifer lithology.

2 The Basic Principles and Steps of Structural Matrix Method

2.1 Fundamentals of Structural Matrix Method

Suppose the weight sum of n apples is 1, and the weights of each apple are w1, w2, w3, ..., wn, respectively. By comparing (dividing) these apples two by two, a comparison matrix (also called a matrix of judgment) representing the relative weight relationship of n apples can be obtained, and the ratio can form a matrix A.

$$\begin{bmatrix} \frac{W_1}{W_1} & \frac{W_1}{W_2} & \cdots & \frac{W_1}{W_n} \\ \frac{W_2}{W_1} & \frac{W_2}{W_2} & \cdots & \frac{W_2}{W_n} \\ \vdots & \vdots & & \vdots \\ \frac{W_n}{W_1} & \frac{W_n}{W_2} & \cdots & \frac{W_n}{W_n} \end{bmatrix} = \mathrm{A} = (a_{ij})_{n\times n} \tag{1}$$

A matrix has the following properties: if it is represented by a vector of weight, then W = (W1, W2, W3,..., Wn)$^{\mathrm{T}}$. If you multiply the A matrix, you get

$$AW = \begin{bmatrix} \frac{W_1}{W_1} & \frac{W_1}{W_2} & \cdots & \frac{W_1}{W_n} \\ \frac{W_2}{W_1} & \frac{W_2}{W_2} & \cdots & \frac{W_2}{W_n} \\ \vdots & \vdots & & \vdots \\ \frac{W_n}{W_1} & \frac{W_n}{W_2} & \cdots & \frac{W_n}{W_n} \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_3 \end{bmatrix} = \begin{bmatrix} nW_1 \\ nW_2 \\ \vdots \\ nW_3 \end{bmatrix} = \mathrm{nW} \tag{2}$$

According to the properties of the matrix, w represents the eigenvector and n represents the eigenvalue. That is, n is an eigenvalue of A, and the weight A of each apple corresponds to each component of the eigenvector of the eigenvalue n. If w is an unknown quantity, the judgment of the ratio can be subjectively obtained according to the relationship between the pairwise comparison of apples by the decision makers, so that A is the matrix of judgment.

The matrix of judgement A has the following traits, which are given below (aij = wi/wj)

(1) $a_{ij} = 1$ (i = j)
(2) $a_{ij} = 1/a_{ji}$ (i, j = 1,2,...,n)
(3) $a_{ij} = a_{ji}$ (i, j = 1,2,...,n)

If the supplied matrix demonstrates the properties of the judgement matrix A (aij = wi/wj) and the aforementioned equation is true, the matrix is entirely consistent. In this case, the biggest eigenvalue of the matrix is max=n, and all other eigenvalues are equal to zero.

The judgement matrix's greatest eigenroot, and $\lambda_{\max} \geq$ n, is typically proven to be a single root.

When the judgement matrix displays acceptable consistency, the maximum eigenvalue slightly exceeds the matrix order n, while the remaining eigenvalues are close to zero. As a result, the Analytic Hierarchy Process (AHP)-based conclusion is often sound.

Complete consistency in judging, however, is not possible due to objective complexity and unavoidable estimating errors when comparing numerous aspects. Eigenvalues and eigenvectors deviate as a result of this.

Although we do not demand perfect consistency in every judgments, we do demand a certain degree of consistency. Thus, a consistency check of the created judgement matrix is required.

When A matrix is completely consistent, because aij $= 1$, $\sum_{i=1}^{n} \lambda_i = \sum_{i=1}^{n} a_{ij} = n$ there is a unique non-zero $\lambda = \lambda_{\max} = n$. When the A matrix judges that there is inconsistency, generally, $\lambda_{\max} \geq n$. At this time, $\lambda_{\max} + \sum_{i \neq \max} \lambda_i = \sum_{i=1}^{n} a_{ij} = n$. Due to $\lambda_{\max} - n = -\sum_{i \neq \max} \lambda_i$.

The consistency index CI of the matrix must be determined in order to evaluate its consistency index CI:

$$C \cdot I = \frac{\lambda_{\max} - n}{n - 1} = \frac{-\sum_{i \neq \max} \lambda_i}{n - 1}.$$

If $\lambda_{\max} = n$, $C \cdot I = 0$, the matrix of judgment is totally consistent; The complete consistency of the judgment matrix deteriorates as its value $C \cdot I$ increases. In general, if the value is $C \cdot I \leq 0.1$, it is considered that the judgment matrix's consistency is satisfactory. If it exceeds this value, it is recommended to redo the pairwise comparison judgment.

When the judgment matrix's dimension n is larger, its consistency tends to decrease, hence the need to relax the consistency requirements for high-dimensional judgment matrices. To assess if the matrix's consistency is satisfactory, it's essential to compare the Consistency Index (CI) with the mean Random Consistency Index (RI). The RI values for matrices ranging from order 1 to 9 are provided in Table 1.

Table 1 Mean random consistency index for orders 1 through 9

Order	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.96	1.12	1.24	1.32	1.41	1.45

Table 2 Judgment scale determination table

Scaling a_{ij}	Definition
1	i is of equal importance to j
3	Factor marginally outweighs j in importance
5	Factor significantly outweighs j in importance
7	i heavily outweighs j in importance
9	i factor is vastly more important than j
2, 4, 6, 8	The scale value corresponds to the condition between the two judgments indicated above.
Reciprocal	When j factor contrasting one i factor with another, the judgement value is $a_{ji} = 1/a_{ij}$

The first-order and second-order judgement matrices' RI are shown in Table 1 to be purely notional because they are always entirely consistent. The consistency index CI of the judgement matrix divided by the average random consistency index RI is known as the random consistency ratio, or CR, for orders greater than 2.

$$C \cdot R = \frac{C \cdot I}{R \cdot I}$$

The judgement matrix is regarded to be suitably consistent when CR is less than or equal to 0.10; otherwise, modifications to the judgement matrix are required. The judgment scales formed by the comparison results of the pairwise importance of each constraint factor in the matrix of judgment are depicted in Table 2.

The adoption of a 1 to 9 scale is justified by: (1) Psychological studies indicate that individuals' ability to discern differences among similar entities ranges between 5 and 9. The scale of 9 reflects the judgm(3) practice shows that the scale of 1 to 9 degree has been fully able to distinguish the various attributes that cause people to feel the difference.

2.2 The Basic Steps of Structural Matrix Method

The Structural Matrix Method comprises four pivotal steps: (1) Formulation of a hierarchical structure model, which requires the identification of the decision-making goal, followed by the classification of goal-influencing factors to erect a multilayered structure; (2) Assembly of a judgment matrix, where the relative importance of each element, in relation to an analogous factor from the preceding level, forms a pairwise comparison matrix; (3) Execution of a consistency test; this step involves calculating and scrutinizing the pairwise comparison matrix's consistency, requiring potential matrix modifications to achieve acceptable consistency; (4) Weight computation; under the assumption of satisfactory consistency test results, the eigenvector corresponding to the maximum eigenvalue of the pairwise comparison matrix is calculated, determining each factor's weight relative to the factor from the preceding level. Ultimately, the comprehensive ranking weight of each factor to the system target is computed, informing the decision-making process.

3 Suitability Zoning

3.1 Build a Hierarchical Model of the System

The system consists of three layers. From the top to the bottom, it is composed of the system target layer (P), the attribute layer (B) as well as the element index layer (M) 3-level hierarchical structure. The P layer is the overall goal of the system, that is, the division of suitable areas for shallow geothermal energy and groundwater heat pumps. Layer A is the attribute index layer, which consists of hydrogeological conditions (Y_1), hydrodynamic conditions (Y_2) and hydrochemical conditions (Y_3), and layer F is the element index layer, which is composed of stratigraphic structure, aquifer water production capacity, aquifer recharge capacity, diving flow field, confined water flow field, groundwater quality, etc., as depicted in Figure 3.

3.2 Construct Matrix of Judgment

According to the requirements of structural matrix approach, based on the system's hierarchical relationship, through survey statistics and indoor research and analysis, the importance of the corresponding element indicators of each layer is judged and compared, and the suitability division

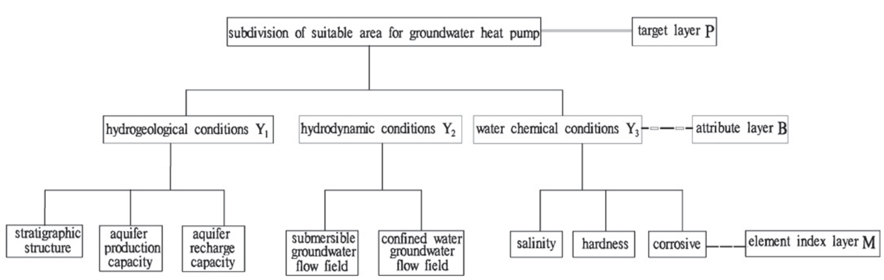

Figure 3 System hierarchical mode.

Table 3 Matrix of judgment of target layer and attribute layer constraint factors

Target Layer P	Hydrogeological Conditions Y_1	Hydrodynamic Conditions Y_2	Water Chemical Conditions Y_3
Hydrogeological conditions Y_1	1	3	5
Hydrodynamic conditions Y_2	1/3	1	2
Water chemical conditions Y_3	1/5	1/2	1

Table 4 Constraining factor matrix of judgment of attribute layer and element index layer

Hydrogeological Conditions Y_1	Stratigraphic Structure	Aquifer Production Capacity	Aquifer Recharge Capacity
Stratigraphic structure	1	1/3	1/5
Aquifer production capacity	3	1	1/2
Aquifer recharge capacity	5	2	1

Continued Table 4 Constraining Factor Matrix of Judgment of Attribute Layer and Element Index Layer

Hydrodynamic Conditions Y_2	Submersible Groundwater Flow Field	Confined Water Groundwater Flow Field
Submersible groundwater flow field	1	3
Confined water groundwater flow field	1/3	1

Continued Table 4 Continued Table 4 Constraining Factor matrix of judgment of Attribute Layer and Element Index Layer

Water Chemical Conditions Y_3	Corrosive	Salinity	Hardness
Corrosive	1	2	3
Salinity	1/2	1	2
Hardness	1/3	1/2	1

of different influencing factors is determined. The influence size of, and the corresponding weights are given. The target layer and attribute layer constraint factor matrix of judgment is depicted in Table 3.

The attribute layer and element index layer constraint factor matrix of judgment is depicted in Table 4.

3.3 Consistency Check

The compute phases of the sum-product approach are used to determine the judgement matrix's outcomes.

(1) Target layer and attribute layer constraint factor matrix of judgment.

① The normalized judgement matrix is obtained by following the sum-product method's calculation steps as follows:

$$\begin{bmatrix} 0.652 & 0.667 & 0.625 \\ 0.217 & 0.222 & 0.250 \\ 0.130 & 0.111 & 0.125 \end{bmatrix}$$

② According to the above steps, adding row by row, we get:

$$\overline{W}_1 = \sum_{j=1}^{n} \bar{b}_{\mathrm{ij}} = 0.652 + 0.667 + 0.625 = 1.944$$

$$\overline{W}_2 = \sum_{j=1}^{n} \bar{b}_{\mathrm{ij}} = 0.217 + 0.222 + 0.250 = 0.689$$

$$\overline{W}_3 = \sum_{j=1}^{n} \bar{b}_{\mathrm{ij}} = 0.130 + 0.111 + 0.125 = 0.366$$

③ Normalize the vector $\mathrm{W} = [1.944, 0.689, 0.366]^{\mathrm{T}}$ to get

$$\sum_{j=1}^{n} \overline{Wj} = 1.944 + 0.689 + 0.366 = 2.999.$$

Then the required eigenvector $\mathrm{W} = [0.648, 0.230, 0.122]^{\mathrm{T}}$

④ The largest eigenroot of the judgement matrix, λmax, is calculated as follows:

$$\mathrm{AW} = \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 2 \\ 1/5 & 1/2 & 1 \end{bmatrix} \begin{bmatrix} 0.648 \\ 0.230 \\ 0.122 \end{bmatrix}$$

$$\lambda_{\max} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{(\mathrm{AW})_{\mathrm{i}}}{\mathrm{nW_i}} = \frac{(AW)_1}{3W_1} + \frac{(AW)_2}{3W_2} + \frac{AW3}{3W3}$$
$$= \frac{1.948}{3 \times 0.648} + \frac{0.690}{3 \times 0.230} + \frac{0.367}{3 \times 0.122} = 3.01 \qquad (3)$$

⑤ Consistency check CI

$$C \cdot I = \frac{\lambda_{\max} - n}{n-1} = \frac{-\sum_{i \neq \max} \lambda_i}{n-1} \tag{4}$$

Calculate Consistency Metrics CI $= \frac{\lambda \max - n}{n-1} = 0.005$. Considering the average random consistency index RI equals 0.58, the judgment matrix's random consistency ratio CR equals $\frac{CI}{RI} = 0.009 < 0.10$, hence indicating the constructed judgment matrix's satisfactory consistency.

(1) matrix of judgment of attribute layer (hydrogeological condition X_1) and constraint factor of element index layer

① The normalized judgement matrix is obtained in accordance with the calculation steps of the sum-product approach as

$$\begin{bmatrix} 0.111 & 0.100 & 0.118 \\ 0.333 & 0.300 & 0.294 \\ 0.556 & 0.600 & 0.588 \end{bmatrix}$$

② According to the above steps, adding row by row, we get

$$\overline{W}_1 = \sum_{j=1}^{n} \overline{b}_{\text{ij}} = 0.111 + 0.100 + 0.118 = 0.329$$

$$\overline{W}_2 = \sum_{j=1}^{n} \overline{b}_{\text{ij}} = 0.333 + 0.300 + 0.294 = 0.927$$

$$\overline{W}_3 = \sum_{j=1}^{n} \overline{b}_{\text{ij}} = 0.556 + 0.600 + 0.588 = 1.744$$

③ Normalize the vector W = $[0.329, 0.927, 1.744]^{\mathrm{T}}$ to get

$$\sum_{j=1}^{n} \overline{W}_j = 0.329 + 0.927 + 1.744 = 3.00.$$

Then the required eigenvector W = $[0.110, 0.309, 0.581]^{\mathrm{T}}$

④ The largest eigenroot $\lambda_{\max}$ of the judgement matrix is determined

$$\mathrm{AW} = \lambda_{\max}\begin{bmatrix}1 & 1/3 & 1/5\\ 3 & 1 & 1/2\\ 5 & 2 & 1\end{bmatrix}\begin{bmatrix}0.110\\ 0.309\\ 0.581\end{bmatrix}$$

$$= \sum_{\mathrm{i=1}}^{\mathrm{n}}\frac{(\mathrm{AW})_{\mathrm{i}}}{\mathrm{nW_i}} = \frac{(AW)_1}{3W_1} + \frac{(AW)_2}{3W_2} + \frac{(AW)_3}{(3W)_3}$$

$$= \frac{0.329}{3\times 0.110} + \frac{0.930}{3\times 0.309} + \frac{1.749}{3\times 0.581} = 3.003$$

⑤ Consistency assessment

The consistency index CI is computed at $C\cdot I = \frac{\lambda_{\max}-n}{n-1} = \frac{-\sum_{i\neq\max}\lambda_i}{n-1}$ CI $= \frac{\lambda\max - n}{n-1} = 0.002$. With the average random consistency index RI at 0.58, the judgment matrix's random consistency ratio CR equals $\frac{CI}{RI} = 0.003 < 0.10$, affirming satisfactory consistency for the constructed judgment matrix.

(2) Matrix of judgment of attribute layer (hydrogeological condition X_2) and constraint factor of element index layer

① The normalized judgement matrix is obtained using the calculation steps of the sum-product approach as follows:

$$\begin{bmatrix}0.750 & 0.750\\ 0.250 & 0.250\end{bmatrix}$$

② According to the above steps, add them by row, and get:

$$\overline{W}_1 = \sum_{j=1}^{n}\bar{b}_{\mathrm{ij}} = 0.750 + 0.750 = 1.50$$

$$\overline{W}_2 = \sum_{j=1}^{n}\bar{b}_{\mathrm{ij}} = 0.250 + 0.250 = 0.50$$

③ Normalize the vector W = $[1.50, 0.50]^{\mathrm{T}}$ to get:

$$\sum_{j=1}^{n}\overline{W}_j = 1.50 + 0.50 = 2.00.$$

Then the required eigenvector W = $[0.75, 0.25]^{\mathrm{T}}$

④ Compute the maximum eigenroot $\lambda_{\max}$ of the matrix of judgment

$$\mathrm{AW} = \begin{bmatrix} 1 & 3 \\ 1/3 & 1 \end{bmatrix} \begin{bmatrix} 0.75 \\ 0.25 \end{bmatrix}$$

$$\lambda_{\max} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{(\mathrm{AW})_{\mathrm{i}}}{\mathrm{nW}_{\mathrm{i}}} = \frac{(AW)_1}{3W_1} + \frac{(AW)_2}{3W_2}$$

$$= \frac{1.50}{2 \times 0.75} + \frac{0.50}{2 \times 0.25} = 2.00$$

⑤ Consistency test

Calculate the consistency index CI

$C \cdot I = \frac{\lambda_{\max} - n}{n-1} = \frac{-\sum_{i \neq \max} \lambda_i}{n-1}$ CI $= \frac{\lambda \max - n}{n-1} = 0$. The judgement matrix's random consistency ratio (CR) equals $\frac{CI}{RI} = 0.\ 0 < 0.10$, given that the average random consistency index (RI) is 0.58. This result verifies the designed judgement matrix's satisfactory consistency.

(3) Matrix of judgment of constraint factor of attribute layer (water chemical condition X_3) and element index layer.

① The normalized judgement matrix is derived as follows using the sum-product method's computing procedures:

$$\begin{bmatrix} 0.545 & 0.571 & 0.500 \\ 0.273 & 0.286 & 0.333 \\ 0.182 & 0.143 & 0.167 \end{bmatrix}$$

② According to the above steps, add them by row, and get:

$$\overline{W}_1 = \sum_{j=1}^{n} \overline{b}_{ij} = 0.545 + 0.571 + 0.500 = 1.616$$

$$\overline{W}_2 = \sum_{j=1}^{n} \overline{b}_{ij} = 0.273 + 0.286 + 0.333 = 0.892$$

$$\overline{W}_3 = \sum_{j=1}^{n} \overline{b}_{ij} = 0.182 + 0.143 + 0.167 = 0.492$$

③ Normalize the vector W = [1.616, 0.892, 0.492]^{T} to get:

$$\sum_{j=1}^{n} \overline{W}_j = 1.616 + 0.892 + 0.492 = 3.00.$$

Then the desired eigenvector W = [0.539, 0.297, 0.164]^{T}

④ The judgement matrix's largest eigenroot, $\lambda_{\max}$, is calculated.

$$\mathrm{AW} = \begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix} \begin{bmatrix} 0.539 \\ 0.297 \\ 0.164 \end{bmatrix}$$

$$\lambda_{\max} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{(\mathrm{AW})_{\mathrm{i}}}{\mathrm{nW_i}} = \frac{(AW)_1}{3W_1} + \frac{(AW)_2}{3W_2} + \frac{(AW)_3}{3W_3}$$

$$= \frac{1.625}{3 \times 0.539} + \frac{0.895}{3 \times 0.297} + \frac{0.489}{3 \times 0.164} = 3.003$$

⑤ Consistency test

Calculate the consistency index CI

$C \cdot I = \frac{\lambda_{\max} - n}{n-1} = \frac{-\sum_{i \neq \max} \lambda_i}{n-1}$ CI = $\frac{\lambda \max - n}{n-1} = 0.0015$. Considering the average random consistency index RI at 0.58, the judgment matrix's random consistency ratio CR equals $\frac{CI}{RI} = 0.0026 < 0.10$, affirming the satisfactory consistency of the constructed judgment matrix.

3.4 Calculate Weights

Each element within the index layer has a ranking weight value that is determined in relation to the topmost layer (total target). Starting with the top layer, this process works its way progressively down to the bottom layer. The results of the computation are shown in Table 5.

4 Results

It can be seen from the final weight ranking in Table 5 that the most influential factors on the results are mainly hydrogeological conditions, followed by hydrodynamic conditions and hydrochemical conditions [15, 16]. Therefore, when dividing the suitability of the groundwater heat exchange system

Table 5 Combination weight calculation results in hierarchical total ranking

Attribute Layer→ / Indicator Layer↓	B_1 (Hydrogeological Conditions Y_1) 0. 648	B_2 (Hydrodynamic Conditions Y_2) 0. 230	B_3 (Water Chemical Conditions Y_3) 0. 122	Indicator Layer M Weight	Weight Ordering
M_1 (stratigraphic structure)	0. 329	/	/	0. 213	3
M_2 (aquifer production capacity)	0. 927	/	/	0. 601	2
M_3 (aquifer recharge capacity)	1. 744	/	/	1. 130	1
M_4 (submersible groundwater flow field)	/	0. 75	/	0. 173	4
M_5 (confined water groundwater flow field)	/	0. 25	/	0. 058	6
M_6 (corrosive)	/	/	0. 539	0. 066	5
M_7 (salinity)	/	/	0. 297	0. 036	7
M_8 (hardness)	/	/	0. 164	0. 020	8

pertaining to shallow geothermal energy ground source heat pump, it should be identified:

(1) Hydrogeological conditions

Identify the geological, hydrogeological conditions and types of groundwater in the work area; the lithology, distribution, depth and thickness of the aquifer; the water bearing and permeability of the aquifer; the direction, velocity and hydraulic gradient of groundwater runoff; groundwater temperature and its distribution; Groundwater quality; groundwater dynamic change characteristics, etc. These elements are the comprehensive manifestation of the water production capacity and the recharge capacity of the aquifer. Table 5 shows that the water output capacity and recharge capacity of the aquifer are necessary conditions to determine whether the location indicated is the one where the ground source heat pump groundwater heat exchange system should be installed. In addition, the different ratios of pumping and filling wells, as well as the construction technology and the well-formed structure, are also inextricably linked to the water production capacity and recharge capacity of the aquifer.

(2) Groundwater dynamic field

Through the study of the groundwater dynamic field, the thickness of the aquifer, the flow of groundwater, the distribution of groundwater falling funnels, and the over-exploitation of groundwater under the current conditions are analyzed to determine the suitability of the groundwater heat pump project and the amount of exploitable resources.

(3) Hydrochemical Field

According to the distribution of groundwater quality, according to the distribution area of urban groundwater sources (or wetlands), combined with the groundwater quality conditions at different levels, the suitability division of groundwater heat pump projects is proposed, and combined with the water quality data at different levels, suitable mining methods to prevent groundwater aquifer pollution are proposed. Recharge level.

5 Conclusion

(1) the water output capacity and recharge capacity of the aquifer are necessary conditions to determine whether the site is the applicable area of the ground source heat pump groundwater heat exchange system.
(2) The depth of groundwater table and grain size distribution are important factors to determine the recharge capacity.

Fund Project

Henan Province Natural Resources Research Project "Research on Exploration and Evaluation Technology of Hidden Hot Dry Rock Resources in Henan Province" (Henan Natural Resources Letter [2020] 542-1) and "Research and Demonstration of Geothermal Resources Monitoring Technology in Henan Province" (Henan Natural Resources Letter [2021] 157-3) and " Research on the Exploration and Evaluation System of Bedrock Thermal Storage in Henan Province" (Henan Natural Resources Letter [2019] 373-12).

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