# Grid-Based Assessment of Groundwater Potential Using GIS

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Abstract: In view of the problem that the weight determination of evaluation indexes in the current groundwater potential assessment was too much affected by human, analyzed the various factors related to the groundwater, constructed a grid-based evaluation index system for groundwater potential assessment, and an assessment model of groundwater potential using GIS based on the evaluation index system, grid-based analysis, entropy weight method combined with artificial experience, Gamma transformation, and natural breakpoint classification method was proposed. The grid-based assessment of groundwater potential in "One Belt And One Road" region was completed, and the favorable areas for water supply were delineated. The results showed that the low, middle and high potential areas of groundwater in the study area account for about 36.00%, 62.30% and 1.70%, and the high potential area was strongly correlated with the location of spring points and water-bearing faults. This evaluation method combined objective weights and subjective experience to reduce the dependence of artificial experience.



## 1 INTRODUCTION

Water is a precious resource for human survival and an important strategic material for national development. Groundwater is an important part of water resources, widely distributed, relatively stable changes, good water quality, groundwater enrichment assessment, can provide a reference for the rational use of water resources, while meeting the demand for water, to avoid further deterioration of the ecological environment, to achieve sustainable economic and social development. (Chen Fei et al., 2020; Yifei Bai et al., 2019; Bin Xu et al., 2018)

The traditional hydrogeological survey method is mainly based on field survey, which is inefficient and difficult to meet the needs of large-scale rapid water finding. Geographic information system technology (GIS) can quickly integrate and analyze large amounts of data, greatly saving manpower and material resources, and improving the efficiency of hydrological work (Cao jianfeng et al., 2006; Saro, Lee et al., 2012; Hema et al., 2017; Demeke et al., 2019). In the assessment of groundwater enrichment, the determination of the weights of each influencing factor is a very critical issue, and the commonly used methods are roughly divided into subjective empowerment method (such as expert scoring method, hierarchical analysis method) and objective empowerment method (such as principal component analysis method, entropy weight method, similarity coefficient method, coefficient of variation method). (Dong Yanhui et al., 2017; Dou Bingchen et al., 2015; Guo Xiaoci et al., 2006) Hema and Subramani (Hema et al., 2017) used topographic maps and LANDSAT TM images to take into account geomorphology, linear density, soil, land use/land cover, river network density, slope and other factors, and used weighted index overlay analysis to draw a groundwater potential zoning map of the study area. Pinto(Pinto et al., 2017)determines the groundwater potential area of comoros basin by using the analytic hierarchy process (AHP) based on river network density, land use, linear density, topography, rainfall, slope, soil, lithology and other factors. Lee (Lee et al., 2012) selected 15 factors related to groundwater and collected data from 44 well locations. Using artificial neural network, he constructed a groundwater production potential model for the surrounding area of Pohang city, South Korea. Pradhan (Pradhan et al., 2021) investigated 145 spring sites to characterize



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groundwater potential, and selected 10 factors to build a deep neural network to explore the groundwater potential area in the Himalayas of Nepal. The subjective empowerment method requires researchers to have rich professional knowledge and practical experience, which is greatly influenced by human subjectivity, and the hydrogeological conditions vary greatly in different research areas, and it is impossible to use the same weight model to evaluate the potential of groundwater richness in different regions, while the objective empowerment method is more dependent on the sample, there is no business experience as a guide, and the weight is easily distorted.

Aiming at the above problems, based on GIS technology, this paper will construct a groundwater enrichment assessment index system, establish a groundwater enrichment personality network assessment model that integrates grid data analysis, entropy weight method combined with artificial experience, Gamma transformation and natural breakpoint classification method, evaluates the groundwater enrichment in the research area, and compares the assessment results with the results obtained by the expert scoring method and the results without reference to artificial experience. The research flow is shown in Figure 1.

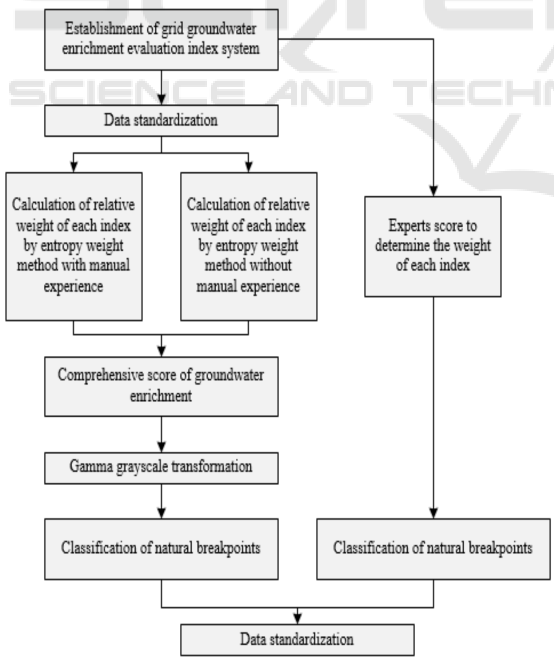



Figure 1: The research flow.

## 2 OVERVIEW AND DATA SOURCES OF THE STUDY AREA

The scope of the study area is (33°N ~ 36°N, 73.5°E ~ 78°E), and the standard division is carried out according to the 1:250,000 scale in the National Standard for division and Numbering of basic Scale Topographic Maps (GB/T 13989-2012).

### 2.1 Overview of the Study Area

The research area includes I43C001002, I43C001003, I43C001004, I43C002003, I43C002004 and I43C003004, as shown in Figure 2. The study area spans three countries, China, Pakistan and India, and is an important area for the implementation of "One Belt and One Road" strategy. It is mainly plateau and mountain, most of which are above 4000 meters above sea level, with numerous rivers and perennial snow in the mountains, which are an important source of groundwater supply in the area. (Ding Jianli et al., 2018)

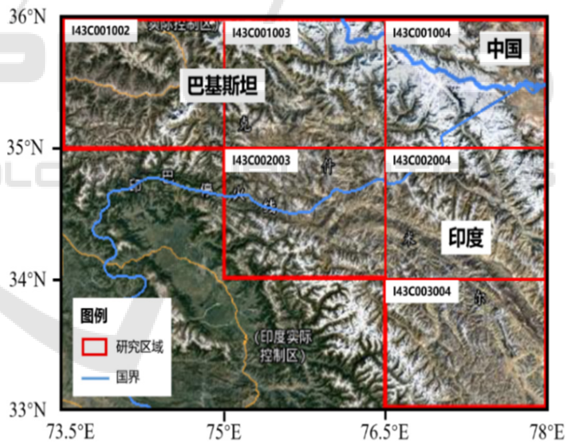



Figure 2: Geographical location of the study area.

### 2.2 The Data Source

The data used in this paper mainly include the following three types :(1) hydrogeological vector files, obtained by visual interpretation of remote sensing images by professionals and provided by xining natural resources comprehensive survey center of China geological survey, including lithology data, water-bearing fracture data, water- bearing fold data, spring point data and overflow zone data; (2) OSM (OpenStreetMap) data, using the river system vector data and road vector data;(3) DEM (Digital Elevation

Model) data reflect the topographic information of the study area.

### 2.3 Evaluation Index Analysis of Groundwater Enrichment

Based on the field investigation results and hydrogeological knowledge, the characteristics of each index and its influence on groundwater are analyzed.

- Lithology

Rock-soil voids are the storage space and transport channel of groundwater. The voids developed by different lithology are different, and the capacity of water storage and transport is also different. There are 19 different lithologies in the study area. According to the field investigation results, the lithology indexes are divided into positive lithology indexes and negative lithology indexes. There are pores in the quaternary unconsolidated layer, which affect the retention, transport and discharge of groundwater. (Zhang Renquan et al., 1980)

- Water-bearing fracture, Water-bearing fold

The fault zone is usually rich in water, and the water-conducting fracture is of great significance to the storage and transport of groundwater. Along the axis of fold, structural fissures are developed and karst is strong, which is beneficial to groundwater collection. High-yield Wells and springs are often related to large linear bodies, intersection points of linear bodies and corresponding structural characteristics, and the occurrence conditions of groundwater in dense linear structures are better. (Quiel, F. et al., 2006)

- Spring, Overflow zone

Springs and overflow zones are the natural ways of groundwater outpouring, which are of great significance to the determination of water-rich (water-carrying capacity) of strata and aquifer or water-repellent layer. In the study area, spring points and spring groups in the form of groundwater discharge are relatively developed and widely distributed. The overflow zone is drained in a linear manner. The overall distribution of the overflow zone in the study area is sparse, mainly located in the middle and northeast of the study area. (Yan Yunpeng et al., 2016)

- Surface water

In the study area, precipitation often occurs in the form of snow and ice in the mountains, and meltwater of snow and ice becomes the main recharge method of surface rivers (Li Penghui et al., 2020), and eventually becomes a large amount of infiltration and transformation into groundwater. Surface water becomes an important or even the only recharge source of groundwater, and its distribution has a great impact on the occurrence, recharge and discharge of groundwater (Wang X F. et al., 2011).

## 3 NETWORK ASSESSMENT MODEL OF GROUNDWATER ENRICHMENT CHARACTER BASED ON GIS TECHNOLOGY

Geographic grid is a grid formed by dividing the earth's surface according to certain mathematical rules. (Ma Ting et al., 2009) With the development of geographic information technology, spatial analysis based on grid management technology is becoming an important technical means in the field of resource management, playing a crucial role in the optimal allocation of natural resources. (Li F Z. et al., 2019)

### 3.1 Establishment of Grid and Groundwater Enrichment Evaluation Index System

The study area was divided into regular grids. Considering the large research scope and sparse distribution of each indicator factor, the size of the selected grids was 3km×3km, and a total of 10212 grids were finally obtained.

Based on the divided grid, grid the source data of the research area:

(1) For point data, the number of points falling into each grid is counted as the value of each grid, such as spring point;

(2) For linear data, the ratio of the length of the line segment in each grid to the area of the grid was calculated as the value of the grid, such as water-bearing faults, water-bearing folds, overflow zones and water systems;

(3) For planar data, the ratio of the area of evaluation indexes in each grid to the area of the grid is the value of the grid, such as quaternary loose bed, lithologic positive index and lithologic negative index. The finally established groundwater enrichment evaluation index system in the study area is shown in Figure 3.

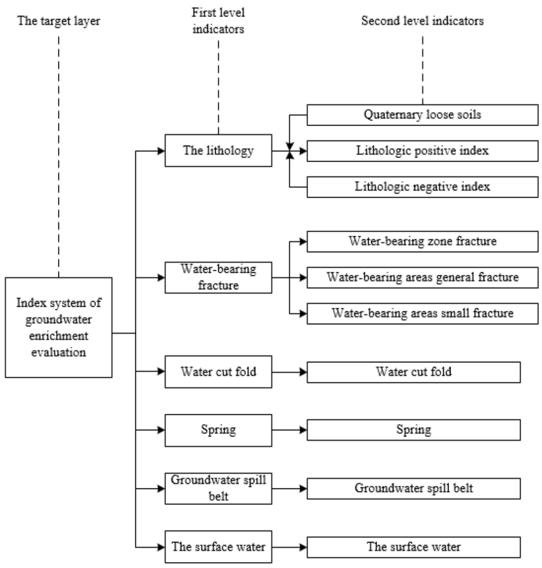



Figure 3: Index system of groundwater enrichment evaluation in the study area.

## 3.2 Entropy Weight Method Combined with Artificial Experience

With *n* evaluation objects and *M* evaluation indicators, the main steps of entropy weight method are as follows :(Lian, S. et al., 2016)

- Standardized

Assuming that the *p*'th index value of the *q*'th object is $v_{pq}$ , and then standardized to $v_{pq}^{'}$ , $v_q$ represents the vector of the *q*'th index, then:

$$v_{pq}^{'} = \frac{v_{pq} - \min\left(v_q\right)}{\max\left(v_q\right) - \min\left(v_q\right)} \text{ (Positive indicators)} \quad (1)$$

$$v_{pq}^{'} = \frac{\max\left(v_q\right) - v_{pq}}{\max\left(v_q\right) - \min\left(v_q\right)} \text{ (Negative indicators)} \quad (2)$$

- Calculate the proportion of item *q*'th in the *p*'th grid:

$$p_{pq} = \frac{v_{pq}^{'}}{\sum_{p=1}^{n} v_{pq}^{'}} (q = 1,2,...,m) \quad (3)$$

- Calculate the information entropy of each index. According to the definition of information entropy, the information entropy of item *q*'th is:

$$E_q = -c \times \sum_{p=1}^{n} p_{pq} \ln\left(p_{pq}\right), c = 1/\ln\left(n\right)\left(q = 1,2,...,m\right) \quad (4)$$

- Calculate the entropy weight. The entropy weight of item *q*'th is:

$$w_q = \frac{1 - E_q}{\sum_{q=1}^{m}\left(1 - E_q\right)} \quad (5)$$

For this study, there are 10212 grids and 10 indicators, namely n=10212, m=10. The evaluation index system of groundwater enrichment in the study area is a two-level index system. In order to avoid weight distortion, the weight of the second-level index to the first-level index will be determined by entropy weight method, and the weight of the first-level index to the target layer will be guided by artificial experience. The weight of the final secondary index is:

$$w_q^{'} = w_q w_{Rq} \quad (6)$$

Where, $w_q$ is the weight of the second-level index to the first-level index, and $w_{Rq}$ is the weight of the first-level index to the target layer. The final evaluation value of groundwater enrichment of each grid is:

$$s_q = \sum_{q=1}^{m} w_q^{'} p_{pq} \quad (7)$$

## 3.3 Gamma Transform

As the overall brightness of the image is too dark and pixel values are mainly concentrated in the dark pixel region, image enhancement is required. In the experiment, a common image enhancement method, Gamma transform, was selected to make the output gray value and the input gray value show an exponential relationship:

$$V_{out} = AV_{in}^{\gamma} \quad (8)$$

Where $V_{in}$ is the input value, $V_{out}$ is the output value, and $A$ is a constant. When $\gamma > 1$, the bright pixel region is stretched and the dark pixel region is compressed; When $\gamma < 1$, the dark pixel region is stretched and the bright pixel region is compressed. When $\gamma = 1$, linear stretching will be done. (Lin Wenpeng et al., 2015)

## 3.4 Classification of Natural Breakpoints

In order to better display the evaluation results, natural breakpoint classification (Jenks, G. et al., 2016; Xu Guiyang et al., 2020), a commonly used classification method, is used to classify the output images after enhancement. It believes that there are some natural turning points or breakpoints in the value of a phenomenon, and these irregular classification limits can divide the data into groups with similar properties. The classification principle of the natural breakpoint method is to compare the variance sum of all classification schemes iteratively, and the smallest is the optimal result.

## 4 RESULTS ANALYSIS

The network assessment model of groundwater enrichment character was constructed by Python and ArcGIS. According to the evaluation index system of groundwater enrichment, the data results of 10 grid indexes were obtained. According to the entropy weight method combined with artificial experience, the information entropy and entropy weight of each evaluation index to the first-level index are calculated, as well as the final relative weight of each evaluation index.

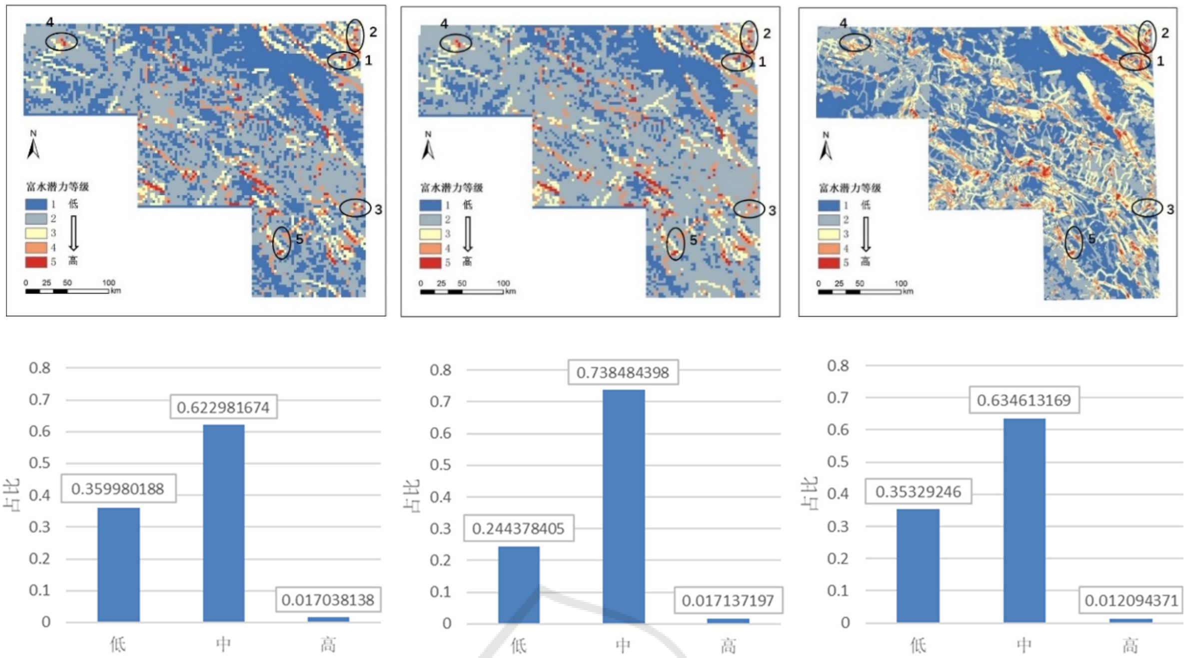
According to the result of entropy weight, in terms of contribution rate to groundwater enrichment in the study area, water-bearing faults, water-bearing folds, springs and overflow zones are more important than lithology and surface water, which is consistent with the weight of first-level indicators given by experts. The final relative weight and entropy weight were respectively used to calculate the groundwater enrichment score of the study area. Gamma transformation was performed on the scoring image by selecting Gamma = 0.2, and the transformed image was stretched to. The natural breakpoint method was used to classify the groundwater enrichment in the final study area by selecting 5 grades, and the assessment results of groundwater enrichment in the final study area are shown in Figure 4 (a), and the assessment results without reference to manual experience are shown in Figure 4 (b). Among them, the water-rich potential of grades 1 to 5 increases successively. The results of expert scoring method were taken as the reference and comparison results provided by Xining Comprehensive Natural Resources Survey Center of China Geological Survey, as shown in Figure 4 (c). The histogram of regional proportion was drawn with Grade 1 as low potential area, Grade 2, 3 and 4 as medium potential area, and Grade 5 as high potential area, as shown in Figure 4. By observing Figure 4, it can be obtained:

- The location distribution of water-rich high-potential areas and water-rich low-potential areas obtained by the evaluation model in this study corresponded roughly with that of the corresponding regions in the reference image, and the proportion of low, medium and high potential areas was basically consistent with that in the reference image. After the addition of manual experience, the evaluation results were improved and closer to the reference results.



Table 1: Weight table of each evaluation index.

| | **First level indicators** | **Weight** | **Second level indicators** | **The information entropy** | **Entropy weight** | **Final relative weight** |
|---|---|---|---|---|---|---|
| Evaluation index system of groundwater enrichment character network | The lithology | 0.1 | Lithologic positive index | 0.950177 | 0.0170941 | 0.00170941 |
| | | | Lithologic negative index | 0.986357 | 0.00468076 | 0.000468076 |
| | | | Quaternary loose soils | 0.916361 | 0.028696 | 0.0028696 |
| | Water-bearing fracture | 0.2 | Water-bearing zone fracture | 0.575037 | 0.145803 | 0.0291606 |
| | | | Water-bearing zone general fracture | 0.713141 | 0.0984198 | 0.01968396 |
| | | | Water-bearing zone small fracture | 0.57495 | 0.145833 | 0.0291666 |
| | Water cut fold | 0.2 | Water cut fold | 0.485504 | 0.176521 | 0.0353042 |
| | Spring | 0.2 | Spring | 0.577541 | 0.144944 | 0.0289888 |
| | Groundwater spill belt | 0.2 | Groundwater spill belt | 0.439394 | 0.192341 | 0.0384682 |
| | The surface water | 0.1 | The surface water | 0.866895 | 0.0456675 | 0.00456675 |




(a) Results of this method

(b) Results without reference to manual experience

(c) Refer to the result

Figure 4: Evaluation results of groundwater enrichment in the study area.

- About 36.00% of the area is assessed as low potential groundwater rich area, mainly distributed in the southwest and north of I43C001004.
- About 62.30% of the area is assessed as groundwater rich potential area.
- About 1.70% of the area is assessed as the water-rich and high-potential area of underground water, which is distributed in the northeast of I43C001004, southwest of I43C002003, southwest of I43C002004, and central of I43C003004. The regions with strong correlation with the location of spring point and distribution of water-bearing faults have higher water-rich potential of groundwater.

# 5 CONCLUSIONS

- The entropy weight of item $q$'th is: In view of the present groundwater enrichment evaluation index weight determining by man's subjective factors affect too much problem, design a subnetted groundwater enrichment character evaluation method based on GIS technology, based on index system is constructed, grid handling analysis, combined with artificial experience of entropy method, and natural Gamma transform breakpoint subnetted groundwater enrichment character evaluation model of classification, The assessment of groundwater enrichment characteristics in the Belt and Road area has been completed.
- This study evaluating method to get the high potential of aqueous area, low potential area and reference images in the corresponding region roughly corresponding to the location of the distribution, low, medium and high potential areas of reference images and is in line with, the evaluation method to the relative weight of the objective and subjective experience guidance, realization of a wide range of groundwater enrichment evaluations.
- About 36.00% of the area is assessed as low potential area with rich groundwater, about 62.30% as medium potential area, and about 1.70% as high potential area. The high potential area has a strong correlation with the location of spring point and water-bearing fracture.

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