GIS-based Suitability Assessment for Shallow Groundwater Development in Zhangye Basin

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Abstract

To provide evidence for groundwater management and development in Zhangye basin, comprehensive evaluation method is used to get suitability assessment. First, assessment indexes system is established, and then, AHP (analytic hierarchy process) is used to evaluate factor weight, at last, the suitability assessment is given by weighted sum using the function of spatial analysis in GIS. The paper gives a comprehensive consideration of exploration condition, aquifer characteristics, recharge condition and groundwater quality according to different water supply targets. In contrast with previous studies which give a general assessment without distinction, the research makes progress on pertinence and suitability.

1. Introduction

GIS has the overlay, re-classification, feature extraction, and other mathematical analysis, which particularly suited for rule-based multiple factors evaluation[1]. Since the 1980 s, GIS was developing very fast in water resources management, and had achieved remarkable results in regional water resources planning and development and utilization of application. Kenneth, K E [2, 3] established exploration and development, simulation, evaluation and management system in GIS environment. A.J.Griner developed water supply protection model in southwest Florida of the American by GIS and established several hydrology, hydrology geology data layer, superimposing produced supply groundwater suitability, surface water supply protection zone, water well supply reserve and groundwater pollution potential area, the last comprehensive formed water supply protection grade division [4]. M.V.V.K amaraju etc
researched groundwater development prospects by GIS in the western region of Godavari in India, considering formation lithology, topography, geological structures and groundwater recharge and so on which controlling the groundwater formation conditions, summarized three hydrogeology unit types with development potential in the region [5].

Zhangye basin has complex hydrogeological and water chemical conditions, and for a long time, due to the unreasonable development and utilization which had caused regional the buried depth of groundwater table fall, springs moved down and a series of geological environment problems. Therefore, the paper had established shallow groundwater development suitability comprehensive evaluation model of Zhangye basin and had important significance to the rational development and utilization of groundwater resources.

2. The general situation in the study area

The study area is located in the middle of Hexi corridor, Qilian mountain south pillow, north in accordance with Longshou mountain, showed landscape with the mountain basin between two mountains, an area of about 2200 km², was the northwest continental climate. Basin was flat terrain, tilted from southeast to northwest, terrain gradient was 25‰-4‰. Aquifer gradually thick, buried depth of groundwater table gradually shallow, particles gradually fine from the piedmont to internal basin. (the buried depth of groundwater table qilian mountain diluvial fan top is greater than 200 m, buried depth of groundwater table is 50-150 m in Longshou mountain piedmont plain, and buried depth of groundwater table is 10-50m to fine soil plain, buried depth of groundwater table is less than 3 m in Heihe river-Shandan river coastal strip), the piedmont single unconfined aquifer area gradually into fine earth plain unconfined-confined water multilayer aquifer structure area [6].

3. The groundwater development suitable assessment model based on GIS

A. Evaluation Method and Process

Comprehensive evaluation method had better adaptability in view of very many factors and its fuzzy composition with the groundwater development suitability controlled. The method processes are: establishing the evaluation index system and then quantitative indexes and determining the factor weights, and then data operation and treatment by some analysis tools (such as the GIS spatial analysis, etc), and finally get suitability assessment.

B. Evaluation Model

1) Evaluation Index System Construction

The construction of the index system is the core of the suitability of groundwater exploitation, the two controlling factors with groundwater dynamic field and hydrogeochemical field are considered according to hydrogeological conditions in research area. 4 first-grade evaluation factors of this evaluation are mining condition, aquifer characteristics, condition of groundwater recharge and groundwater quality. Moreover, condition of groundwater recharge considers groundwater update rate and the surface water system influence as second-grade evaluation factors, groundwater quality consider mineralization and fluorine content as second-grade evaluation factors.

(1) Exploration condition

The buried depths of groundwater table in alluvial proluvial fan piedmont of Qilian mountain are more
than 200m, but the buried depths of groundwater in fine soil plain are less than 5m in the study area, therefore, The buried depths of groundwater table is the main factor to influence mining conditions. At the same time, the buried depth of groundwater is a certain effect to groundwater recharge. According to different buried depths of groundwater in the study area, quantitative indexes will be divided into five levels: < 25m, 25 to 50 m, 50-100 m, 100-200 m, > 200 m (see table 1).

(2) Aquifer characteristics

Aquifer characteristics mainly depend on transmissivity and specific storativity of aquifer. Because the study area is larger, above two parameters is lack in most areas, but water yield property of aquifer is the comprehensive reflection of transmissivity and specific storativity. So aquifer characteristics were characterized by aquifer water yield property. According to different aquifer water yield property in the study area, quantitative indexes will be divided into five levels: < 1000 m$^3$/d, 1000-3000 m$^3$/d, 3000-5000 m$^3$/d, > 5000 m$^3$/d (see table 2).

(3) Condition of groundwater recharge

The factors effect groundwater recharge include river and canal recharge, irrigation recharge, precipitation recharge, groundwater inflow, etc in the study area. Through groundwater balance calculation, river and canal recharge accounted for 67.3%, groundwater inflow accounted for 28.6%, and irrigation recharge accounted for 2.6%, precipitation infiltration accounted for only 1% or so.

Due to complex groundwater recharge factors, and some factors planar distribution parameters are difficult to get,

So groundwater recharge ability was comprehensive characterized by groundwater update rate. In addition, because recharge of the Heihe river and canal accounted for 67.3%, the surface water recharge can be made one of evaluation factors (see table 3).

(4) Groundwater quality

On the basis of groundwater quality and data material, two factors of salinity and fluorine ion were considered. Industrial and agricultural water were mainly influenced by groundwater salinity, domestic water were mainly influenced by high fluorine groundwater (see table 4).

2) Data Normalization

In order to quantitative calculate different influence factor, each factor need to be made standardized treatment that is given a certain value within the scope of the quantitative values. The standardized quantitative indexes take 0-5.

The formula of standardization quantitative is generally:

$$Q_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}} \times 5$$

Qi- one of evaluation factors standardization value

Xi- one of evaluation factors code value

Xmax- one of evaluation factors the biggest code value

Xmin- one of evaluation factors the least code value

<table>
<thead>
<tr>
<th>The buried depths of groundwater table (m)</th>
<th>&gt;200</th>
<th>100-200</th>
<th>50-100</th>
<th>25-50</th>
<th>&lt;25</th>
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<tbody>
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<td>code</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
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Table 2 aquifer characteristics classification standardization table

<table>
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<th>aquifer water yield property (m³/d)</th>
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<th>3000-5000</th>
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Table 3 condition of groundwater recharge classification standardization table

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<tr>
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<td>standardization value</td>
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Table 4 groundwater quality classification table standardization

<table>
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<th>fluorine (mg/L)</th>
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<td>1.67</td>
<td>3.33</td>
<td>5</td>
</tr>
</tbody>
</table>

According to the influence degree of groundwater development suitability, the score of every factor was classified into 5 grades in ascending order. The greater the score, the better the suitability, and vice versa (see table 1-4).

3) Determination of Evaluation Factors’ Weight

Based on different water supply target, the value of the factor weight is diverse. Considering water resources characteristics in the district, shallow groundwater is mainly applied to agricultural irrigation and domestic water of countryside villages and towns. The weight of groundwater quality is greater for domestic water. The weights of exploitation conditions, groundwater recharge and aquifer properties are greater for agricultural irrigation. Because the weight has great influence on evaluation result, the evaluation factors’ weight is determined by analytic hierarchy process (AHP).

Firstly, invited the colleague experts to discuss the evaluation index and work out expert consultance form. On the basis, constructed judgment matrix by analysising relative importance of each two factors. Secondly, tested the consistency and randomness of the judgment matrix. The testing formula was

\[ CR = \frac{CI}{RI} \]

Among them, CR was random coincidence coefficient of the judgment matrix, CI was consistency index of the judgment matrix, which was calculated by the following formula:
Among them, $K_{\text{max}}$ was the largest eigenvalue, $n$ was order of the judgment matrix, which was an empirical value. When $CR<0.1$, the judgment matrix was satisfactory consistency and the weight was reasonable. Otherwise, need to adjust the judgment matrix until got satisfactory consistency.

According to the principle and steps of AHP, every factor weight of A scheme (industrial and agricultural water) and B scheme (drinking water) was acquired by calculation (see table 5).

4) Mathematical Model

After weight calculation, using the function of spatial analysis of arcgis to establish mathematical model, based on the above evaluation index system and data standardization. Got the evaluate result through analyzing of spatial data overlay and weight calculation of attribute.

The valuation model used weighted sum method, the mathematical model was:

$$CI = (K_{\text{max}} - n)/(n - 1)$$

$$MQ = \sum_{i=1}^{n} w_i \cdot c_i \quad (i = 1, 2, \ldots, 5)$$

$MQ$ - the comprehensive index of development potential;

$W_i$ - the factor weight value;

$C_i$ - the standardized value of impact factor.

C. Evaluation Result

The result of shallow groundwater exploitation suitability evaluation was obtained through the above evaluation model in study area. The comprehensive index of Industrial and agricultural water was 0.210-4.910, the comprehensive index of domestic water was 0.781-4.763. The groundwater exploitation suitability was equally divided into four grades: available development zone, fairly available development zone, fairly unavailable development zone and unsuitable development zone. The suitability evaluation of groundwater development of industrial and agricultural water and domestic water (see fig 1, fig 2).
Fig 1 Suitability evaluation of industrial and agricultural water development

About industrial and agricultural water: the groundwater available and fairly unavailable development zone, which centered at Zhangye city and Ganjun, Daman, Hongshawo villages were as boundary. The
characteristics included better water-abundance, shallow buried depth of groundwater (<50m) and better development condition. Unsuitable development zone located at foreland pluvial fan top in southern and northern area, buried depth of groundwater >150m, worse water-abundance, which go against large scale development and utilization. So give priority to canal irrigation, and to consider well irrigation at the same time. The middle transitional zone of alluvial and flood fan was fairly unavailable development zone.

About domestic water: in southern area of Jingan-Zhangye farm, the mineralizer was less than lg/L, fluoride content was less than lm/L, good water quality, buried depth of groundwater was less than 150m, which was easy to exploit domestic water. The fairly available development zone located at southern area of foreland pluvial fan top, the minerlizer was moderate, fluoride content was low, but buried depth of groundwater was generally more than 200m. The shallow groundwater mineralizer and fluoride content both exceeded the national standards for drinking water in the northeastern of study area, which was considered as fairly unavailable development zone. The Hongshawo village hereabout was unsuitable development zone, fluoride content was 2~4 mg/L, where the improved drinking water and disease prevention work was important.

4. Conclusion and discussion

1) Build the suitability assessment model of shallow groundwater based on arcgis. Evaluation indexes included groundwater quality, exploitation conditions, aquifer properties and groundwater recharge conditions. The evaluation model was the model of weighted sum about the above factors, and the output results were the degree division map of groundwater suitability development.

2) In the salt-fresh water mixed zone or groundwater polluted area, because poor quality water uniformly effected industrial and agricultural water and domestic water, generally evaluated the groundwater suitability development. According to the different influence degree of high fluorine water, separately evaluated the groundwater suitability development for the different supplied water. Comparing with traditional evaluation, it improved the method and result.

3) The multi-source information comprehensive evaluation model was further improved with data accumulation and regeneration. At the same time, the paper only studied the development suitability of phreatic water area, multilayer structure shallow phreatic water and confined water. The development suitability of multilayer structure deep confined water remained to analysis in the future, which will provide the perfect technologic support for the reasonable exploitation of groundwater in study area.

References:


