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Assessment Of Karst Groundwater Vulnerability In Jinan Area Based On DIKW Model

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Abstract:
Groundwater resources play an irreplaceable role in the ecological environment and social and economic development. The antifouling performance evaluation of groundwater can identify high-risk areas of groundwater pollution, and provide a strong decision-making basis for groundwater protection. Based on the DRASTIC model, DRTA model and DLCT model, combined with the physical geography and hydrogeological conditions of the Jinan study area, this paper selects the depth of the aquifer, the lithology of the vadose zone, the permeability coefficient of the vadose zone, and the degree of karst development. Based on the evaluation factors, a karst groundwater vulnerability evaluation model—DIKW model was proposed. The DIKW model is used to evaluate the antifouling performance of the karst groundwater system, and the zoning map of the antifouling performance of the karst groundwater is obtained. The results show that the areas with poor antifouling performance and poor performance are mainly located in the southern mountainous area, accounting for 46.31 % of the area . The regions with the middle and upper reaches of antifouling performance are mainly located in the alluvial plain of the Yellow River and the piedmont plain, accounting for 53.69 % of the area .

Key words: *karst groundwater; antifouling performance evaluation; antifouling performance index; Jinan City*

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I. Introduction

Groundwater resources play an irreplaceable role in the ecological environment and social and economic development. For Jinan, which takes "Spring City" as its tourist and cultural name card, groundwater resources are not only related to the economy and people's livelihood, but also have special and far-reaching significance for this city. meaning.

The spring water supply in Jinan mainly depends on the atmospheric precipitation in the southern mountainous area. The precipitation infiltrates into the ground through surface runoff, forming fissure karst water. The fissure karst water flows northwestward along the inclination of the strata, encounters the intrusive rock mass in the urban area, and the groundwater is exposed to the surface under pressure, forming the world-famous spring water in Jinan[1].

But in recent years, with the continuous increase of human activities, the risk of karst groundwater pollution is also increasing. As the society pays more and more attention to the protection of the ecological environment, in order to prevent the continuous emergence and deterioration of groundwater environmental problems in karst development areas, it is urgent to continuously improve and improve new evaluation methods for groundwater environmental problems.

Groundwater antifouling performance, also known as groundwater vulnerability, the evaluation of groundwater antifouling performance can judge the degree of groundwater pollution risk, and provide reference and basis for the protection of groundwater ecological environment. This paper will discuss the antifouling performance evaluation of Jinan karst groundwater.

II. Overview of the study area

Scope of the study area

the distribution area of carbonate rocks in the Pingyin monocline on the north wing of Mount Tai , Changqing-Xiaolipu monocline, Baotu Spring, Baiquan and Mingshui springs , involving Liaocheng District Dong'e County, Changqing District , Shizhong District, Licheng District, Huaiyin District, Lixia District, Zhangqiu District, Pingyin County under the jurisdiction of Jinan City, and Zichuan District and Zhoucun District under the jurisdiction of Zibo City. The four extreme coordinates are 116°00′~118°00′ east longitude, 36°00′~36°50′ north latitude, with an area of about 4922 km ^{2} .

Overview of the study area

The study area is located at the junction of the alluvial plains in northwest Shandong and the low mountains and hills in central Shandong, with the Yellow River alluvial plains and piedmont plains in the north, and a part of Mount Tai in the south. From south to north, there are Zhongshan, low mountains, hills, intermountain plains, piedmont sloping plains and Yellow River alluvial plains[2].

Structurally speaking, the study area is located on the north wing of the dome of Mount Tai. Generally, the Paleozoic strata are the main body, and it is a large-scale monocline structure that slopes gently to the north. The strata in the area are relatively well developed, with basement rock series and caprock distributed, belonging to a dual structure. In terms of tectonics, it straddles the Northwest Depression of the Second New China Subsidence Zone and the Luxi Uplift of the Second New China Uplift. In the south is a north-dipping monocline structure dominated by Paleozoic strata, and in the north is a depression area where thicker Quaternary and Neogene loose deposits were deposited[3].

in the area can be divided into five categories, namely: loose rock-like pore-water water-bearing rock groups, clastic rock-like fissure-water water-bearing rock groups, carbonate rock fissure-karst water-bearing rock groups, clastic rocks with carbonatite karst - Fissure water-bearing rock formations, massive rock-type water-bearing rock formations . The karst groundwater in the area mainly comes from the infiltration recharge of atmospheric precipitation, and other sources include Quaternary pore water recharge, surface water seepage recharge, lateral runoff recharge, and farmland irrigation reinfiltration recharge, etc. The flow direction of the karst groundwater is roughly the same as the inclination direction of the formation, and it moves from south to north after receiving recharge[4]. Excretion methods mainly include spring water excretion, quaternary excretion and artificial mining.

Distribution of soluble rocks

There are three types of karst areas in the study area, namely buried karst areas, covered karst areas and exposed karst areas.

1. Bare type

It is an area where the thickness of the local overlying layer is less than 1m and the carbonate rocks are exposed on the surface, including the karst water system in the Mingshui spring area, Baiquan spring area, Baotu spring area, Changxiao monoclinic karst water system. The groundwater in the exposed area mainly moves vertically after being recharged by atmospheric precipitation.

2. Covering type (with 30m as the boundary, divided into deep burial and shallow burial description)

where the overlying caprock is Quaternary, the underlying strata are carbonate rocks, and the caprock thickness is greater than 1m. Widely distributed in the piedmont sloping plains and the alluvial plains of the Yellow River in the northern part of the work, part of which zigzags along the intermountain valleys in the southern mountains.

According to the lithological characteristics of the Quaternary overburden and combined with the geomorphic conditions, the overburden karst area can be described separately with a boundary of 30m. Overburden karsts with Quaternary overburdens less than 30m thick are mainly distributed in the piedmont plains and valleys in the southern mountainous area. From south to north, the burial of soluble rocks gradually deepens. Quaternary overburdens with a thickness greater than 30m are mainly distributed in the alluvial areas of the Yellow River. Plain area.

3. Buried type

Refers to the upper part of the underlying carbonate rocks, which are successively covered with Quaternary cap rocks, Paleogene or other non-dissolvable rock formations. There are few buried karst areas in the working area, and most of them are scattered. Specifically The distribution is as follows: the Wangjiazhai area in the north of the karst water system division of the Mingshui spring area, the Chongshan and Xibaoshan water source areas in the east; the Mengjiawo area and the Xingwangzhuang area in the east of the Baiquan spring area karst water system division area are sporadic; The northern part of the Changxiao monocline karst water system is distributed in a relatively large area, located between the Mashan fault and the Niujiaodian fault, and distributed in the area of Xilong-Wujiadu-Niujiaodian[5].

III. Evaluation of antifouling performance of karst water system

Evaluation Model

In 1968, Margat first proposed the concept of "groundwater vulnerability"[6], also known as groundwater anti-fouling performance. The evaluation of groundwater pollution vulnerability can identify high-risk areas of groundwater pollution and provide a strong decision-making basis for groundwater protection. The U.S. Environmental Protection Agency (EPA) proposed a DRASTIC model that can be used to evaluate groundwater antifouling performance in 1987[7]. The DRASTIC model was proposed by the U.S. Environmental Protection Agency in 1987. The seven indicators are: Depth (D), net recharge (R), aquifer medium (A), soil medium (S), terrain slope (T), vadose effect (I), and hydraulic conductivity (C).

However, this method has mixed reviews and has certain limitations[8]. According to the actual situation, domestic experts and scholars have proposed many improvements on the basis of the DRASTIC model[9], such as the DRITC model[10], The DRICS model [11], the DRUA model[12] for evaluating karst groundwater in Jinan area were developed.

Combined with the analysis of the actual situation in the study area, this paper proposes a model for evaluating the overall antifouling performance of the study area . The gas zone permeability coefficient and the degree of karst development are used as evaluation factors, and the calculated index values are expressed in DIKW, which is tentatively called the DIKW index method.

Water level buried depth (D): The buried depth refers to the depth from the surface to the water level line of karst water. It is a very important factor because it determines the depth to which pollutants migrate before reaching the aquifer, the length of contact time with the rock and soil in the vadose zone, and the various physical and chemical processes that pollutants undergo, which in turn determines the pollutant Potential for intrusion into karst water. Generally speaking, the deeper the karst groundwater is buried, the longer it takes for pollutants to migrate, and the more opportunities to be oxidized by oxygen in the vadose zone, the greater the degree of attenuation of pollutants, and the greater the probability of being diluted. The chances of successfully reaching the karst groundwater are smaller.

Lithology of vadose zone (I): The medium of vadose zone is one of the most significant factors affecting the antifouling performance of karst water. Its role is mainly manifested in the degree of development of fissures and the thickness of grains. Fine grains and less developed fissures , the speed of pollutant migration is slower, and it is easier to be adsorbed by the surrounding medium, and various physical and chemical reactions in the process of pollutant migration will be more sufficient, and the antifouling performance will be better.

For the vadose zone, the medium with the best antifouling performance and a thickness greater than 1m should be selected for scoring. The antifouling performance of the medium is ranked as follows: clay, silt → loam → loam, mudstone → silt, argillaceous shale → silt, shale → igneous rock, metamorphic rock → silt and clay Gravel, fine sand, sandstone, weathered igneous rock and metamorphic rock→limestone with few cracks and karst pores, medium-coarse sand→gravelstone with little silt and clay→basalt→limestone with karst development.

Permeability coefficient of the vadose zone (K): The permeability coefficient of the vadose zone strongly affects the recharge of surface infiltration, and also affects the ability of pollutants to migrate vertically to the vadose zone, mainly related to the cohesive soil layer near the surface in the vadose zone Related, the cohesive soil layer in the vadose zone is distributed continuously, and the smaller the permeability coefficient, the better the antifouling performance.

Water-richness of karst aquifer (W): The main factors affecting the degree of karst development are stratum lithology (rock properties, structure and chemical composition), geological structure and other factors. The water-richness largely reflects the development of karst The area with high degree of karst development tends to have better water richness.

Weight value

The weight value is given according to the impact of the aforementioned evaluation factors on the antifouling performance of the karst water system .

Table 1 Weight assignment table of evaluation factors for groundwater pollution susceptibility

Evaluation index	Weights
Groundwater depth (D)	3
Air-encapsulated medium (I)	5
Permeability coefficient of vadose zone (K)	5
Water richness of karst aquifer (W)	2

Indicator categories and scoring

First, divide each factor category in the DIKW model. Factors D and K are numerical categories, and factors I and W are medium categories; on this basis, each category of each factor is scored, and the value range is 1-10 , the best antifouling performance is 1, and the worst is 10 (Table 2).

Table 2 Assignment of water level and buried depth

Water level buried depth (m)	assignment	Water level buried depth (m)	assignment
< 3	10	20～30	4
3～5	9	30～40	3
5～10	7	40～60	2
10～20	5	> 60	1

Table 3 Lithology assignment of vadose zone

Lithology of vadose zone	assignment
Clay, igneous rock, metamorphic rock	1
Silty clay, loess-like soil	2
Thin dolomite limestone interbedded with shale	4
gravel mixed with silty clay	6
gravel layer	8
Karst developed limestone	10

Table 4 Assignment of permeability coefficient of vadose zone

Cohesive soil permeability coefficient	Thickness>1m and continuous distribution
$K>10^{-4}$ cm/s	10
10^{-6} cm/s$\leq K \leq 10^{-4}$ cm/s	5
$K<10^{-6}$ cm/s	1

Table 5 Grading assignment of water-richness

water-rich grade	assignment
$W \leqq 100$	1
$100<W \leqq 500$	3
$500<W \leqq 1000$	5
$1000<W \leqq 3000$	7
$W \geqq 3000$	10

Calculation of antifouling performance index and classification of antifouling performance

The formula for calculating the antifouling performance index DI is:

DI=3×D+5×A+5×C+2×K

According to its calculation index, the antifouling performance level is divided according to the following standards, among which diving is divided into five levels: strong antifouling performance, strong, medium, poor, and poor.

Table 6 Grading table for evaluation of karst groundwater pollution easily

grading	Karst groundwater	
I	DI<50	Strong antifouling performance
II	50≤DI＜70	Strong antifouling performance
III	70≤DI＜90	Medium antifouling performance
IV	90≤DI＜110	Poor antifouling performance
V	DI≥110	Poor antifouling performance

Extraction of traits of regional evaluation indicators

(1) Groundwater depth (D)

This indicator mainly selects the survey data of groundwater depth in the wet season (horizontal annual high water level) in the study area in 2019, and divides the depth of water level into 8 grades. The areas with buried water level ≤ 3m are mainly distributed in the alluvial plain along the Yellow River; the areas with buried water level of 3-5m are mainly distributed in Yushan Town, Luzhuang of Guide Town, Yizhuang of Ping'andian Town, and Daxinzhuang of Tianqiao District. Daming Lake in the Lower District, etc.; the area with a buried water level of 5-10m is widely distributed in the north of the Yellow River, Lengzhuang, Ping'andian Town, and Fengqi Village; the area with a buried water level of 10-20m is mainly distributed in the southern part of Pingyin County Piedmont plains; areas with water levels buried at a depth of 20-30m are mainly distributed in Yinjialin Village and Dougou Village of Dangjiazhuang Town, Baigudui Village of Suncun Town, Xizaoyuan Village of Guodian Town, etc.; water levels buried at a depth of 30-40m The area is mainly distributed in the valleys of Dongzang Village, Songliugou Village, Wufengshan Town and Shuangquan Town of Xiaozhi Town; the area with a water level buried at a depth of 40-60m is mainly distributed in the intermountain valleys and piedmont plains in the southern mountainous area; the water level The areas with buried depth > 60m are mainly widely distributed in the southern mountainous area and the piedmont plain.

(2) Lithology of vadose zone (I)

This indicator uses the collected engineering geological drilling data, field investigation and drilling results, and combines the contents of the "Shandong Province Engineering Geological Map (1:500,000)" for comprehensive analysis. Clay, silty clay, and loess-like soil are mainly distributed in the alluvial plain in the north of the Yellow River and the piedmont plain in the north; along the Yellow River, there are sandy gravel mixed with silty clay and sandy clay; In the area of Xibaoshan and Chongshan, on the north bank of the Yellow River between Xiaolipu fault and Niujiaodian fault, there are clastic salts such as thin dolomite limestone interbedded with shale. The exposed karst limestone is widely distributed in the south.

(3) Permeability coefficient of vadose zone (K)

The soil zone medium refers to the uppermost part of the vadose zone, where the biological activity is relatively strong. The soil zone medium strongly affects the recharge of surface infiltration, and also affects the ability of pollutants to migrate vertically to the vadose zone.

The Quaternary and Tertiary soil belts in the work area are mainly sandy clay, clayey sand, silt and silt,

which can be scored on behalf of the soil belt medium. In the alluvial plain in the north of the Yellow River and the piedmont plain in the north, the permeability coefficient is 10^{-6} cm/s≤K≤10^{-10} cm/s ; along the Yellow River, there are sand and gravel mixed with silty clay, and the permeability coefficient is 10^{-1} cm/s≤K≤10^{-2} cm/s ;
The empirical values of the permeability coefficients of various soils are as follows: (cm/s).

Table 7 Range value of soil permeability coefficient (unit: cm/s)

soil name	Permeability coefficient	soil name	Permeability coefficient
coarse sand, gravel	a×(10^{-1}~10^{-2})	Silt	a×(10^{-4}~10^{-6})
Middle sand	a×(10^{-2}~10^{-3})	Silty clay	a×(10^{-6}~10^{-7})
fine sand, silt	a×(10^{-3}~10^{-4})	clay	a×(10^{-7}~10^{-10})

(4) Water richness of karst aquifer (W)

This indicator mainly refers to the "People's Republic of China 1:50000 Hydrogeological Map Specification Jinan City Sheet", "Shandong Province 1/250,000 Regional Hydrogeological Environmental Geological Survey Report (Jinan City Sheet)" and other contents for comprehensive analysis. The area along the Yellow River is generally rich in water. The water abundance near the Dong'e and Pingyin County basins is 1000-3000m ^{3}/d, and the water abundance near the Changqing to Jinan basins can reach more than 5000m ^{3}/d; the water abundance in the Piedmont Plain It is about 500-1000m ^{3}/d; the intermountain plain and exposed limestone in the southern mountainous area are less than 500m ^{3}/d.

Evaluation results of antifouling performance

By superimposing and calculating the four indicators of the DIKW model, the following antifouling performance evaluation chart is obtained. According to the actual situation of the study area, it is divided into four levels. DIKW score ≥ 110 is an area with poor antifouling performance, which is very easy to be polluted; 90 ≤ DACK score < 110 is an area with poor antifouling performance, which is easy to be polluted; 70 ≤ DACK score 90 is an area with medium antifouling performance, which is moderately easy to pollute; 50≤DACK score<70 is an area with strong antifouling performance, which is less prone to pollution; DACK score<50 is an area with good antifouling performance, which is not easily polluted.

The antifouling performance classification of karst groundwater in the working area is shown in Table 8. The area with poor antifouling performance accounts for 40.30% of the total area, and the area with poor antifouling performance accounts for 6.01% of the total area. The antifouling performance is medium The area with strong antifouling performance accounts for 25.49% of the total area, and the area with strong antifouling performance accounts for 19.83% of the total area.

Table 8 Statistical table of karst groundwater antifouling performance zoning area in the working area

Evaluation partition	Area (km ^{2})	Area ratio (%)
Strong antifouling performance area	863.5194	19.83%
Strong antifouling performance area	1109.7612	25.49%
Medium antifouling performance zone	364.3113	8.37%
Poor antifouling performance area	261.7121	6.01%
Poor antifouling performance area	1754.6449	40.30%
total	4353.9489	100.00%

The evaluation results show that the strong, strong and poor areas of karst groundwater antifouling performance in the study area are widely distributed, accounting for 19.83%, 25.49% and 40.30% of the area, which is quite different from the geological structure in the study area. , Mountains and hills coexist with alluvial plains and have an inseparable relationship.

Most of the areas with poor anti-fouling performance of karst groundwater are distributed in the southern mountainous area of Jinan. This area is an exposed soluble rock distribution area of clastic rocks intercalated with carbonatite karst-fissure water-bearing rock formations . Pollutants can directly enter the karst formations through fissures. It is very easy to be polluted, and it is also a direct supply area for spring water in Jinan.

The area near the Yellow River is distributed with sand and gravel layers along the river , and pollutants are easy to seep into the ground. At the same time, it is located in the discharge area of fissure karst water groundwater runoff. The water level of karst water fluctuates in the Quaternary loose layer, and the water level is relatively shallow . Poor area.

The areas with strong and strong antifouling performance of karst groundwater are generally distributed in the extensive alluvial plains and piedmont plains in the north of the Yellow River. Protective effects.

The areas with medium antifouling performance of karst groundwater are mainly distributed in the transition zone between the poor zone and the good zone near the Yellow River, and the intermountain plain zone in the southern mountainous area. The Quaternary caprock in the intermountain plain is slope diluvial, mainly composed of loess-like silty clay, sand and gravel layers, etc., and has a dual structure. Compared with the alluvial plains, the Quaternary caprocks in the intermountain plains are looser, have greater porosity, more complex composition, poorer water abundance, and deeper water table buried depths. Generally, the good and medium areas are the main areas. host.

In the general trend, the boundaries of each district are generally divided along the Yellow River and the southern mountainous areas, showing that from southeast to northwest, the antifouling performance of karst groundwater gradually transitions from poor areas to strong and strong areas. The antifouling performance of karst groundwater in the study area is mainly affected by the lithology and permeability coefficient of the protective caprock. Excluding the area along the Yellow River where the gravel layer is distributed, the area overlying the Quaternary clay and silty clay caprock is generally obtained. The higher the antifouling performance evaluation is.

IV. Conclusions

Based on the actual situation of karst water and groundwater in Jinan, this paper evaluates the antifouling performance of karst groundwater in Jinan. From the evaluation results, the areas with poor antifouling performance of karst groundwater in Jinan are widely distributed, and the evaluation of antifouling performance of karst water is generally in the south. Low in the north and high in the north, relying on extensive Quaternary sediments in the north can effectively protect the karst groundwater, while the exposed karst in the southern mountainous area is more likely to be polluted and is a direct supply area for groundwater. Once pollution occurs, the karst groundwater in the entire region will be affected. It is imperative to strengthen the environmental protection of the exposed soluble rock distribution areas in the southern mountainous area.

A variety of evaluation models have been proposed for the evaluation of groundwater antifouling performance in China, but because the evaluation factor values are closely related to the local hydrogeological parameters, there is no method suitable for all regions. In the same region, different factors and the value of the weight will also lead to different results. The DIKW model is more focused on the research on the overburden of karst water. The results obtained in this paper aim to propose a new evaluation method for reference. For the evaluation of the antifouling performance of Jinan karst groundwater, there is still a lot of room for further deepening and development in the future .

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