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Evaluation of Groundwater Vulnerability with Improved DRASTIC Method

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Abstract

The groundwater pollution in many regions is becoming more and more serious because of over-exploiting and industrial activities. Typically, the groundwater system in intensive planting area is facing with serious threat of pollution from over-using of fertilizer. In this paper, AHP (Analytic of Hierarchy Process) method was used to reset the weights of DRASTIC parameters referring to the conditions of intensive plantation in Jiangyin city and to evaluate the groundwater vulnerability. The results show that the groundwater in most of the study area was susceptible to pollution; A minor of area is less susceptible to the groundwater pollution. The evaluation results for groundwater quality is consisted with the actually situation in study area. The work is helpful in guiding a theoretical and practical regulation for groundwater resource.

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Keywords: DRASTIC model; groundwater; vulnerability mapping; evaluation

Introduction

With increase of fertilizer use and the rapid development of population, agriculture cultivation is becoming more intensive, and its scale is becoming much larger while land-use efficiency has been fully exploited. The nitrate pollution of groundwater caused by agricultural activity and a substantial increase in fertilizer utilization is also becoming an increasingly problem. Different from surface water, groundwater has a slow update cycle and a weak self-purification capacity, once it is contaminated, the removal, treatment, rehabilitation of polluted groundwater are very difficult, which need a heavily investment, high technology, and a long period of time. Groundwater vulnerability study is the important work for the rational development, utilization and protection of groundwater resources, and it has become a key issue in the field of international hydro-geological research in recent years. Through the study of groundwater vulnerability, difference between the vulnerability of groundwater in different regions can be learned to evaluate the potential easy contaminated of groundwater, and to delineate the scope of groundwater vulnerability area, which can alert people that effective preventive and protective measures

should be taken at the same time with the development and utilization of groundwater resources in vulnerable areas.

Study area

Jiangyin city is located in the lower reaches of the Yangtze River. It belongs to Wuxi city. The total area of Jiangyin city is 987.5 square kilometers and the cultivated area is 62.64 hectares, and 49.31 hectares of this city is paddy field, 12.73 hectares is dry land. The aquifers in study area is generally 8-10 meters and less permeable. The single well water yield is generally less than 10 m³ /day and the water depth is 1.0-3.0 meters. Phreatic aquifer is recharged from precipitation and surface water supplies, and annual amplitude of the impact of rainfall on groundwater recharge is about 1 meter.

Methodology of evaluation

In DRASTIC model, 7 parameters which influent and control groundwater flow and contaminant transport are listed as a comprehensive evaluation of groundwater vulnerability. They are depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone, conductivity of the aquifer. While using DRASTIC to evaluate groundwater vulnerability, an appropriate map is selected firstly and they are divided into a number of evaluation units to determine the hydrogeological conditions of each unit according to existing actual data of the area. Based on this information, the rate and weight of each hydrological unit is determined and then be put together by the seven factors to calculate the vulnerability index. The formula is as follows:

$$\text{DRASTIC vulnerability index VI} = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w.$$

In the formula, the subscript *w* is weight, *r* is rate, the vulnerability index is weighted sums of rate of all the evaluation factors. Once the DRASTIC vulnerability index is calculated, relative vulnerability of groundwater of each unit can be determined. The regional vulnerability index is larger, its groundwater is relatively more susceptible to pollution, and vulnerability is relatively higher. It should be specially noted that the DRASTIC index does not mean the absolute value of groundwater pollution; it is only means the relative vulnerability of groundwater in different regions.

Table 1 Basic information table of study area's shallow groundwater

Town	Depth of groundwater level (m)	Recharge of groundwater(mm)	Type of soil
Huangtu	1-2.5	19.57	Clay
Ligang	1-2.5	18.43	clay loam
Shengang	/	20.71	clay loam
Xiagang	/	18.43	clay loam
Yuecheng	1-3.5	13.81	clay loam
Qingyang	1.5	12.66	clay loam
Xiake	1.5-2.5	14.97	clay loam
Huashi	4-5	12.67	silty soil
Zhouzhuang	1.5	18.43	silt loam
Xinqiao	2.5-3	17.27	silty clay
Changjing	2-3	16.13	clay loam
Gushan	1-3	14.96	loam
Zhutang	4-6	13.80	clay loam
Nanzha	1.5	11.50	silt loam
Yunting	2-2.5	12.66	clay loam
Chengjiang	2-3	11.50	clay loam

The study of groundwater vulnerability aims at distinguishing differences in groundwater

vulnerability level of different regions, guiding people to protect groundwater resources when exploit it, striving to achieve the sustainable use of water resources. From this perspective, groundwater vulnerability indicator can reflects the self-protection of groundwater environment, and assess potential pollution prone of groundwater quantitatively. According to the specific circumstances of the area, and reference to other relevant research results of groundwater vulnerability, the degree of groundwater vulnerability can be divided into five levels: not vulnerable, slightly vulnerable, generally vulnerable , relatively vulnerable and extremely vulnerable (Table 2).

Table 2 Classes of groundwater vulnerability assessment

Classes of vulnerability	1	2	3	4	5
Degree of vulnerability	not vulnerable	slightly vulnerable	generally vulnerable	relatively vulnerable	extremely vulnerable

Results and discussion

In this paper, AHP (Analytic Hierarch Process) method was used to determine weights of evaluation factor. The method combines qualitative and quantitative analysis together to deal with various decision factors and it has a flexible and simple system, so it is widely used in all fields of social economy. According to the actual situation and the definition from U.S. National Research Council (NRC), the special vulnerability of groundwater is vulnerability referring to special pollution sources or pollution, or human activity. To research the special vulnerability of groundwater of Jiangyin city, the first thing to consider is the impact of agricultural input factors on groundwater. In this area, agriculture cultivation is intensive, fertilizer input is dense, and nitrate pollution threat is serious. Therefore, we select groundwater nitrate concentration index as factors, which typically represent fertilizer input factors. Similarly, according to AHP, we can determine the weight of the special vulnerability assessment factors, and further to the weight of special vulnerability impact factors. The weight of the optional elements is calculated according to a certain standard. There are two calculating methods of judgment matrix weights: the geometric mean method (root method) and normative column average method (and method). We select the geometric mean method. Firstly, we calculate the product of each element in each row, calculate the nth root of the product, then normalize the vector; the vector is the weight vector of the request. After the judgment matrix is structured, we apply it to calculate relative weight of each element for a particular criterion layer, and do the consistency test. Although the structure does not require the determination with complete consistency, excessive deviation from the consistency of judging is not allowed. So we do the consistency test. Consistency ratio is calculated by.

$$CR = CI/RI.$$

Where, *CI* is the consistency index of calculating, λ_{max} is the largest eigenvalue of matrix *A*. *RI*: average random consistency index. For *n* = 1, 2... 9, 10, the corresponding value of *RI* was shown in Table 3:

Table 3 RI values

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

According to the relative importance of each element in the same level, we can calculate the overall comprehensive weight of elements at all levels as shown in Table 4.

Table 4 Comprehensive weight of groundwater vulnerability assessment factor

		evaluation index	relative weight	weight
topography	0.038	terrain slope	1	0.038
		soil media	0.35	0.091
		vadose zone media	0.40	0.121
stratum	0.302	aquifer media	0.15	0.045
		hydraulic conductivity of aquifer	0.15	0.045
		recharge of groundwater	1	0.044
recharge of groundwater	0.044	recharge of groundwater	1	0.044
depth of groundwater	0.116	depth of groundwater	1	0.116
special vulnerability index	0.500	special vulnerability index	1	0.500

In this paper, we take the distribution of groundwater nitrate concentrations map as the special vulnerability factors to make nature vulnerability assessment system into specific vulnerability assessment system, then sum all the score values up by weight. The comprehensive vulnerability assessment level of the area is shown in Table 5.

Table 5 The division table of comprehensive vulnerability assessment attainment

vulnerability index	assessment	vulnerability	vulnerability degree	vulnerability level
≤55.6		hard-contaminated	low	I
55.7~61.3		relatively hard-contaminated	relatively low	II
61.4~63.3		relatively easy-contaminated	medium	III
63.4~65.0		easily contaminated	relatively high	IV
≥65.1		highly easy-contaminated	high	V

Summing all the score values up by weight, we get the nature vulnerability assessment results shown in Figure 1. From this figure, we can find two highly hard-contaminated areas, which is 12.5% of total areas; two highly easy-contaminated areas, which is 12.5% of total areas; two relatively hard-contaminated areas, which is 12.5% of total areas; five relatively easy-contaminated areas, which is 31.3% of total areas; five easily contaminated areas, which is 31.3% of total areas. Overall, the level of nature vulnerability of this area is in middle class. It must be noted that the vulnerability is just a relative concept, which is derived from considering the vulnerability of groundwater level. From the view of total area, not easily contaminated area is small, which is only 7.85% of total area; highly easy-contaminated area is 14.46% of the total area; easily contaminated area is 32.38% of the total area; relatively easy-contaminated area is 36.65% of the total area; relatively hard-contaminated area is 8.65% of the total area.

Although some areas belong to not easily contaminated areas of nature vulnerability, their groundwater vulnerability is also strong for the impact of human activities, such as Shengang town and Zhutang town, which have a high values of groundwater nitrate. So we should consider the impact of special vulnerability factors. We selected nitrate Index as the special vulnerability factor, combined with nitrate concentration distribution diagram, we got the evaluation results of specificity diagram, shown in Figure 2. From the evaluation results, we can see that Gushan Town has the highest level of water quality and is less susceptible to pollution; Huangtu town and Ligang town have a low level of water quality and are easily polluted area. The towns with a class III level water.

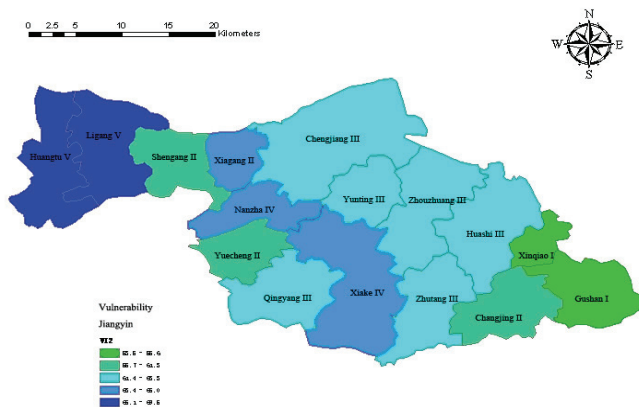


Fig.1 Groundwater’s nature vulnerability assessment results of Jiangyin city

Ligang town have a low level of water quality and is easily polluted area .The towns with a class III level water quality correspond to the level of vulnerability for Class III, or a difference of level. Xiake town has a class IV of water quality and vulnerability; Changjing town has a class III water quality and Class II vulnerability level; Shengang town has a class IV water quality and class II vulnerability level, the large difference may has a collection with nitrate pollution factors. Overall, the vulnerability evaluation has a good agreement with the actual water quality.

From figure 2, we can find that the results of special vulnerability evaluation diagram are as same as the nature vulnerability evaluation diagram in highly easy-polluted and not easily polluted areas. Changjing town with a large change varies from nature vulnerability level IV to special vulnerability level II; Qingyang town varies from nature vulnerability level IV to special vulnerability level III; Chengjiang town varies from nature vulnerability level IV to special vulnerability level III; other towns’ level is as same as the level of nature vulnerability. The reason may be that the groundwater of some towns is significantly affected by human activities, especially by fertilizer application factors. Under natural conditions, groundwater only controlled by the internal nature hydro-geological conditions, groundwater chemistry evolution in time and space is mainly affected by three elements: the aquifer material composition, transferring utility and alternating utility. The ability of groundwater against pollution depends on the nature vulnerability. The impact of human activities changed the original hydrogeochemical environment, and made the groundwater environment more vulnerable.

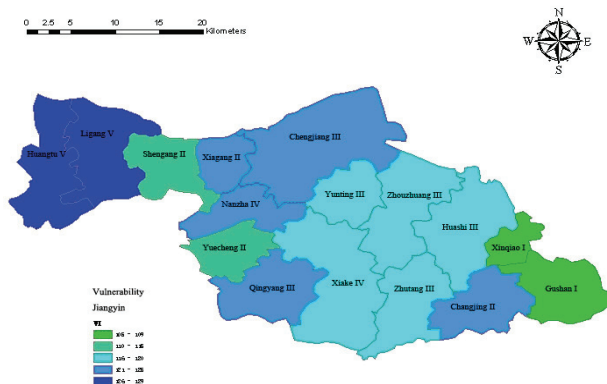


Fig.2 Groundwater’s comprehensive vulnerability assessment results of Jiangyin city

Conclusions

AHP method was used to improve and re-identify the weight of index in method DRASTIC. The evaluation results show that most areas of Jiangyin city are relative easy-contaminated area, and a few areas are not easily contaminated area. The comprehensive vulnerability assessment results demonstrate the groundwater level of vulnerability against main pollutants reasonably.

From the comparison of evaluation results of special vulnerability and nature vulnerability, it can be seen that the results of special vulnerability evaluation results are as same as the nature vulnerability evaluation results in highly easy-polluted and not easily polluted areas. Changjing town with a large change varies from nature vulnerability level IV to special vulnerability level II; Qingyang town varies from nature vulnerability level IV to special vulnerability level III; Chengjiang town varies from nature vulnerability level IV to special vulnerability level III; other towns' level is as same as the level of nature vulnerability. The reason is that the groundwater of some towns is significantly affected by human activities, especially by fertilizer application factors.

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