Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 12	No. 1	pp. 99-103	2013

Original Research Paper

Study on Groundwater Environment Health Evaluation Based on Rough Set

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 25-9-2012
Accepted: 5-11-2012

Key Words:
Groundwater environment health
Rough set
Evaluation index system

ABSTRACT

The paper puts forward the idea of groundwater environment health and constructs an evaluation index system for the groundwater environment health according to the connotation of groundwater environment health. The 17 evaluation indexes were simplified to obtain the most simple evaluation index system through the simplification function of the rough set, and then the weight of the evaluation index was calculated through the weight calculation function of the rough set, and the quantitative evaluation of groundwater environment health was carried out by means of a comprehensive index method. The evaluation results show that the attribute simplification and weight calculation of the rough set can be applied to the comprehensive evaluation of hydrogeology.

INTRODUCTION

By combining with the function of groundwater, the groundwater environment health can be defined as follows: the groundwater environment health characterizes the state of the groundwater system and the capacity for the stability and sustainability thereof while maintaining its own resources ecological, geological and environment functions. The correct characterization of groundwater environment health refers to the correct quantitative and qualitative description for the state of groundwater environment. However, the problem of how to determine the health degree of groundwater environment is an urgent problem to be studied and resolved. In the study, an evaluation index system, which is capable of comprehensively reflecting the state of groundwater environment health, will be adopted to complete the evaluation.

The evaluation of groundwater environment health is a complicated, nonlinear and high dimension evaluation process, wherein the acquisition of essential data is limited, and most of the current comprehensive evaluation methods cannot solve the problem for the comprehensive evaluation of small sample and high dimension (Jiang 2007, Sheng 2008, Zhang 2001). As a new method of data mining, the redundant index can be removed through the attribute simplification principle of rough set, and defects of two weight determining methods, i.e., subjective and objective weight determining methods by calculating the objective weight of each index according to the rule of the data and combining with the subjective weight (Qin 2006, Cao 2006). In theory, the rough set can solve the problem of multi-index selection and weight calculation, so that the rough set is applied to the study of comprehensive evaluation (Lin 2006, Pawlak 1991). This paper evaluates the groundwater environment health of the study area by means of the attribute simplification and weight calculation functions of the rough set.

OVERVIEW OF GROUNDWATER ENVIRONMENT HEALTH IN THE STUDY AREA

Geographical position of the study area: The groundwater system for the above-ground segment of Yellow River is defined according to the width and depth for the supply of Yellow River water to the groundwater, wherein the width for the water supply of above-ground segment of Yellow River is 5 to 20km, and the depth of water circulation is less than 350m. The relevant studies have shown that the northern and southern boundaries for the groundwater system of Henan Province are the actual supply range of the Yellow River to the groundwater respectively, i.e., the expansion for the two sides is 5 to 20km based on the axis of modern Yellow River (Sheng 2008, Cao 2006, Lin 2006). The area located on the Yellow River Lower Reaches Suspend River Section is 1062.20km^2, namely 14.15% of the administrative region in Zhengzhou area.

Establishment for evaluation index system of groundwater environment health: The evaluation index and grading standard of groundwater environment health shown in

Table 1, are established by referring to earlier preliminary studies (Sheng 2008).

ROUGH SET THEORY

The basic concept of rough set theory has been involved in a lot of literature, the paper focus on the point of how to implement the simplification and index weight calculation for the evaluation index of the rough set theory, wherein the simplification of the evaluation index is carried out mainly by means of the attribute simplification and core theory of the rough set theory (Slowinski 1992). The weight of the index is calculated according to the knowledge dependence and the attribute importance of the rough set, and the details for the specific calculation principle are as follows:

Simplification of Evaluation Index

Knowledge simplification: The simplification of knowledge is one of the core problems in the rough set theory; for the knowledge acquisition based on the rough set theory, the minimization of the decision table is carried out mainly by simplifying the original decision table.

In any knowledge representation system S = {U, R, V, f}, if r_0 **X** R, and in (R-{r_0}) = ind (R), it can be claimed that the attribute r_0 is redundant in R, i.e. r_0 is a redundant attribute; otherwise, it can be claimed that r_0 is absolutely necessary in the R. If each attribute r **X** R is absolutely necessary in R, it can be claimed that the attribute set R is independent, otherwise, it can be claimed that the R is simplified.

The algorithm of attribute simplification can be described as the following steps: calculate the equivalence relation of condition attribute; calculate the upper and lower approximations of each equivalence relation in relation to the decision table calculate the value of ξ according to the heuristic function: $x = (|\overline{B}(x)| - |\underline{B}(x)|)/|U|$, and select the attribute with the smallest value of ξ as the attribute to be retained necessarily; repeat the process of attribute section, select the attribute to be retained necessarily, and generate a new equivalence relation by combining rest attributes with the attributes of the simplified set red at every time, wherein the heuristic function is applied to the relations as the reference point of attribute section, and the algorithm will be recursively applied until the predetermined domain is an empty set.

Core: Attribute simplification refers to the minimum and essential subset of the relation, and the core of the attribute refers to the most important relation set. In the R, the set composed of all the absolutely necessary attributes is known as the attribute core of R, and denoted by core (R). Core (R) = ∩ red (R), in which red (R) indicates all the simplifications of R, and it can be interpreted as an essential knowledge characteristics set during the knowledge simplification process (Shang 2005, Wang 2005, Chen 2005).

In the evaluation, the simplification of evaluation index refers to the determination of the attribute core.

Calculation for the weight of evaluation index: According to the concept for the dependence of knowledge, the dependency level of the knowledge R to the knowledge P is defined as follows:

$$Y_P(R) = \frac{\sum_{[x]_R \in (U/R)} card(\underline{P}[x]_R))}{card(U)} \quad ...(1)$$

In the formula, card (U) indicates the tendency of the set U, and also can be written as |U| usually; P indicates the number of the elements contained therein, 0 ≤ YP (R) ≤ 1. When YP (R) = 1, the knowledge of R is totally dependent on the knowledge Q, when YP is close to 1, it can indicate that the dependence level of the knowledge R to the knowledge P is high, and therefore the size of YP(R) can reflect dependence level of the knowledge of R to the knowledge of P. For the importance of attribute subset x ⊆ X of classification exported from the attribute set R, we measured that with the dependence level there between, i.e.

$$\sigma_R(x_i) = Y_X(R) - Y_{X-\{xi\}}(R) \quad ...(2)$$

According to the meaning and calculation principle of weight, we can derive the calculation formula of objective weigh from the importance formula for the attribute the rough set:

$$\omega_i = \frac{\sigma_R(x_i)}{\sum_{i=1}^{n} \sigma_R(x_i)} \quad ...(3)$$

According to the formula (3), the objective weight ω_i of any of the evaluation index x_i can be calculated.

As the objective weight calculated according to the rough set theory put too much emphasis on the data, the method of subjective determination method can be used during the process of objective weight calculation of the rough set in the paper to obtain a more reasonable attribute weight. Corresponding to each attribute, the comprehensive weight is calculated by solving a subjective weight (ωi') by means of a subjective determination method, adding the adjustment parameter η (0 ≤ η ≤ 1), and combining with the objective weight. Therefore, the derived formula of the comprehensive weight (ω_0) is as follows:

$$\omega_0 = \eta\omega_i' + (1 - \eta)\,\omega_i \quad ...(4)$$

In the formula, η reflects the preference of the decision maker to the objective weight and subjective weight of each

Table 1: Evaluation index and grading standard of groundwater environment health.

Index	Unit	Evaluation Criteria		
		Health	Subhealth	Unhealth
C_1 Annual GDP growth rate	%	7.75	7.25	6.75
C_2 natural population growth rate	%	0.2	1.5	2.0
C_3 Water consumption for the GDP output value of ten thousand Yuan	$m^3/10^4$Yuan	35	75	150
C_4 Industrial water consumption for the output value of ten thousand Yuan	$m^3/10^4$Yuan	15	30	50
C_5 Quota of irrigation water	m^3 /Mu	180	250	350
C_6 Proportion of agricultural water	%	55	73	80
C_7 Modulus of surface water resources	$10^4m^3/(km^2{\cdot}a)$	80	45	17
C_8 Modulus of recoverable groundwater resources	$10^4m^3/(km^2{\cdot}a)$	30	20	10
C_9 Natural protection capability of groundwater	Dimensionless	2 stronger	3 general	4 weaker
C_{10} Water resource shared per capita	m3/person	800	600	400
C_{11} Development and utilization degree of water resources	%	40	50	75
C_{12} Modulus of groundwater mining	$10^4m^3/(km^2{\cdot}a)$	2	5	10
C_{13} Mining the degree of groundwater	%	40	70	90
C_{14} Comprehensive pollution index of surface water	Dimensionless	0.4	0.7	1.0
C_{15} Total hardness of groundwater	mg/L	300	450	550
C_{16} Decline rate of shallow groundwater level	m/a	0	0.2	0.5
C_{17} Comprehensive evaluation of groundwater quality	Dimensionless	2	4	5

Table 2: Information system of Zhengzhou study from 1998 to 2007.

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}	c_{11}	c_{12}	c_{13}	c_{14}	c_{15}	c_{16}	c_{17}
x_1	7.85	0.82	192.55	220.00	72.00	245.00	56.92	7.50	46.46	118.22	13.12	28.24	4	0.73	252.39	0.44	3.32
x_2	8.00	0.77	139.87	210.00	69.00	234.00	56.61	13.68	34.13	162.45	12.04	65.43	4	0.79	252.39	0.41	3.33
x_3	9.40	0.73	204.24	200.00	66.00	191.30	55.07	8.07	44.63	111.42	11.87	26.59	4	0.83	269.95	0.34	3.36
x_4	9.10	0.69	141.38	190.00	56.00	229.00	53.59	4.38	32.01	167.30	13.40	41.86	4	0.81	236.61	0.39	3.37
x_5	9.50	0.60	152.84	180.00	161.00	209.00	55.70	3.86	21.10	160.09	15.05	71.33	4	0.79	272.85	0.41	3.39
x_6	10.50	0.56	324.75	130.00	130.00	170.00	61.74	18.03	43.94	55.76	12.74	29.01	4	0.76	269.96	0.48	3.40
x_7	13.70	0.52	256.21	100.00	103.00	176.00	46.68	22.25	42.34	82.41	12.68	29.95	4	0.88	276.95	0.47	3.47
x_8	14.10	0.53	254.21	110.00	98.00	185.00	55.48	8.05	43.28	110.42	11.25	27.62	4	0.77	226.61	0.35	3.42
x_9	14.10	0.53	267.44	110.00	98.00	170.00	35.94	14.43	47.35	80.47	12.50	26.45	4	0.72	262.84	0.32	3.44
x_{10}	14.40	0.49	255.21	90.00	96.00	185.00	48.68	21.57	41.79	83.45	13.59	30.25	4	0.71	294.95	0.45	3.50

attribute during the decision-making process, wherein the larger η indicates the preference of the decision maker to the subjective weight of the attribute, and the smaller η indicates the preference of the decision maker to the objective weight (Zeng 1996, Wang 1998, Zhang 2007, Xiao 2004).

EVALUATION FOR GROUNDWATER ENVIRONMENT HEALTH IN THE STUDY AREA

In the study work, the evaluation is carried out by means of the various index data of the evaluation area from 1998 to 2007, wherein the specific evaluation steps are as follows: Firstly simplifying the evaluation index, calculating the weight of the evaluation index, and then quantifying and implementing qualitative evaluation for the groundwater environment health in the evaluation area by means of a comprehensive index method.

Simplification of evaluation index: In the information system S = {U, R, V, f} of the rough set, $R = C \cup D$ indicates an attribute set, the subsets C and D are respectively called as condition attribute and decision attribute, wherein U indicates Zhengzhou study area, C indicates the specific value of each index, and the establishment of the decision attribute D can be prevented during the attribute simplification and weight calculation process.

In order to facilitate the calculation, the specific values are replaced by the following codes, specifically x_1, x_2, …, x_{10} are used for replacing the values from 1998 to 2007; c_1, c_2, ..., c_{17} are used for expressing the 17 index values, the sequence thereof is in line with the previous sequence, and the information system of the calculation constructed therein is given in Table 2.

Calculation for the attribute simplification of rough set of the established information system, in which $U = \{x_1, x_2, \ldots, x_{10}\}$ and $R = \{c_1, c_2, ..., c_{17}\}$ according to the rough set theory, the simplified indexes of Zhengzhou study area are $\{c_7, c_8, c_{12}\}$. The additional consideration of warning of the study aims at finding out the environment problem of groundwater, selecting the indexes which are capable of revealing the problems of groundwater environment health in the study area, and finally selecting the simplified attribute set Q = {c_4, c_7, c_8, c_{12}, c_{17}} and U = {x_1, x_2, ..., x_{10}} to form a new knowledge space, wherein the simplified index system is the most simple evaluation index system.

Weight Calculation of Evaluation Index

Calculation of objective weight: According to the formulae 1 and 2, the importance 0.8 of the attribute r_7 can be calculated, and the importance 0.6 of the attribute c_{12} can be calculated; and the objective weights of the three attributes can also be calculated according to formula (3), i.e. ω_7 = 4/11, ω_8 = 4/11, and ω_{12} = 3/11, respectively.

Calculation of comprehensive weight: Firstly determine the final subjective weights, i.e. $\omega_4' = \omega_{12} = \omega_{17}' = 3/11$ and $\omega_7' = \omega_8' = 1/11$ of the five index according to the expert consultation method, wherein the comprehensive marks for the subjective weights of the three indexes, i.e. the water consumption for the GDP product value of ten thousand Yuan, the mining degree of groundwater, and the quality of the groundwater. According to the formula (4), when η = 0.6, and the comprehensive weights determined by means of calculation are as follows: ω_{04} = 0.164, ω_{07} = 0.2, ω_{08} = 0.2, ω_{012} = 0.273, and ω_{017} = 0.164.

Evaluation for groundwater environmental health in study area: The comprehensive index for the groundwater environment health in the study area can be calculated by means of the comprehensive index on the basis that the weight of the evaluation index is obtained, the state of the groundwater environment health is classified according to the established comprehensive index grading standards, wherein the established comprehensive index grading standards for the groundwater environment health in the study area are given in Table 3, and then the calculated comprehensive index is compared with that in Table 3 to obtain evaluation results for the groundwater environment health in the study area as given in Table 4.

The evaluation results show that the groundwater environment of the study area is sub-health in most years, the groundwater environment in 1999, 2001 and 2002 is ill-health, and the groundwater environment in 2004 and 2006 is healthy only.

According to the attribute simplification function of the rough set, the C_3 water consumption for the GDP output value of ten thousand Yuan, C_6 proportion of agricultural water, C_7 modulus of surface water resources and C_{12} modulus of groundwater mining are the most important among the evaluation indexes for the groundwater environment health of the study area, they cannot be simplified, which indicates that the impact for the supply and demand of the groundwater resources on the groundwater environment in the study area

Table 3: Comprehensive index grading standards.

Health Level	Unhealth	Subhealth	Health
Comprehensive Index	(0-0.5)	(0.5-0.75)	(0.75-1.0)

Table 4: Diagnosis result for groundwater environment health state in serial years of the study area

Year	Comprehensive Index	Diagnosis Result
1998	0.504	Subhealth
1999	0.354	unhealth
2000	0.524	Subhealth
2001	0.404	unhealth
2002	0.197	unhealth
2003	0.621	Subhealth
2004	0.754	Health
2005	0.573	Subhealth
2006	0.785	Health
2007	0.715	Subhealth

is large, and is in line with the water supply condition based on the overexploitation of groundwater in the area.

In the evaluation results, the grade of groundwater environment health of 1999 to 2002 is the worst, and the reason thereof is the overexploitation of groundwater in case of the interruption of the Yellow River and a large number of groundwater environments are in the worst state; but the groundwater environment health state in the study area is batter since 2004, the reason thereof is continuous wet year and prevented interruption of the Yellow River and other aspects, and so that the groundwater environment health state in the study area is good. Therefore, it can be indicated that the evaluation results can truly reflect the groundwater environment state in the study area and also can reflect the influence of external forces on the groundwater environment.

CONCLUSIONS

The attribute simplification and weight calculation functions of the rough set theory can be applied to the evaluation of groundwater environment and mainly applied to the simplification of evaluation index and the calculation of the weight. Therefore, the workload for the calculation of comprehensive evaluation can be properly reduced, and the accurate weight can be obtained.

The evaluation results for the groundwater environment health in the study area show that the groundwater environment of the study area is sub-health in most years, the groundwater environment in 1999, 2001 and 2002 is ill-health, and the groundwater environment in 2004 and 2006 is health only.

According to the analysis, the evaluation results can truly reflect the health status of the groundwater environment in the study area, the feasibility of the rough set to the comprehensive evaluation is proved, and the rough set can be analogized to other comprehensive evaluations.

ACKNOWLEDGEMENTS

Supported by Scientific Research Foundation for the doctoral graduates of Xinjiang University (BS110129).

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