CHINESE GEOGRAPHICAL SCIENCE
Volume 5, Number 1, pp.87–96, 1994
Science Press, Beijing, China

WATER QUALITY ANALYSIS AND ASSESSMENT OF RIVERS IN JILIN PROVINCE OF CHINA

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ABSTRACT: By means of principal component analysis, based on 6 principal components chosen of computer, cluster analysis of the river water quality in Jilin Province was made objectively. Based on chosen principal components, the river water quality in Jilin Province was evaluated by means of synthetic index method, fuzzy mathematical method, and grey correlation. Rivers in Jilin Province are polluted differently. The rivers polluted most seriously make up 44.4%, the rivers polluted seriously make up 25.9%, and the rivers polluted lightly make up 18.5%. Judging by synthetic pollution indexes of water quality, the first five rivers polluted seriously are the Yitong River, the East Liaohe River, the main branch of the Tumen River, and the Gaya River(tributary of the Tumen River). The rivers with good water quality are the Piaohe River, the Jiaohe River, the Buhatong River and the main branch of the Yalu River. The waters polluted comparatively seriously in Jilin Province are the sections of rivers passing through cities and towns. The main pollutants are organic compounds. And the main reason causing serious water pollution is the discharge of industrial and domestic wastewater.

KEY WORDS: principal component analysis, cluster analysis, water quality analysis, water quality assessment

Water is the main factor for environmental state and the important resources for mankind living. Water is the resources with moving state, and its physical-chemical features actively changes in ecological circle. So, we should pay attention to the benefits in using water and to the environmental problems caused by the variation of water condition during developing water resources. In the paper, the water quality was analyzed and assessed for rivers in Jilin Province with modern technological procedures in order to find out the variation rule of river water quality in Jilin Province, which is referred as science foundation for the application and protection of water resources in Jilin Province.

I. INTRODUCTION TO HYDROLOGICAL FEATURES OF WATER IN JILIN PROVINCE

Jilin Province with a total area of 118, 486 km^2, is located in the middle of north region, 40 ° 52– 46 ° 18 ′ N and 121 ° 38 ′ –131 ° 18 ′ E. The terrain run from southeast to northwest, classifying three sections, the east Changbai Mountains, low middle hilly land and the west Songliao Plain. Baitoufeng is the principal peak of the Changbai Mountains, the water resource of the Songhua River, the Yalu River and the Tumen River. There are 221 rivers with 30 km length, belonging to five big water systems of the Heilong River, the Liaohe River, the Tumen River, the Yalu River and the Suifen River. The precipitation is the main source for the river water.

Although water resource is abundant in Jilin Province, the distribution is not balanced in region, big change in a year period, water quantity is large in the middle of southeast Hunjiang River, and the Yalu River, precipitation is 850–1000 mm in a normal year, runoff depth is 400–550 mm in a normal year; the next is the Toudao and Erdao Songhua River; but that is small in west plain, river water the whole quantity of river water is most in the Second Songhua River, runoff quantity is 17,500 million m^3 in a normal year, being 43% of the total runoff quantity of the whole province; the next is the Yalu River and the Tumen River, being 17% and 14% 0f the total runoff quantity of the whole province respectively.

Content of sand in rivers is closely related with factors of rainstorm strength, topography, soil and vegetation. The East Liaohe River is the most in sand content in Jilin Province, mean erosion modulus of a year in its upper section is 1000 ton/ km^2 a year; the smallest is the Changbai Mountains in erosion modulus.

II. WATER QUALITY ANALYSIS OF RIVERS IN JILIN PROVINCE

In order to find out water quality state, based on the collection of Environmental Monitoring Center of Jilin Province in 1989, the comprehensive information of 27 rivers (Fig.1), 220 sections and 28,630 data were treated with principal component analysis [1].

1. Principal Component Analysis of River Quality

The original water quality data were inputted into computer, calculation were carried on principal component program[2]. The accumulating percentage of used feature value is over 85%, all of six principal components were chosen.

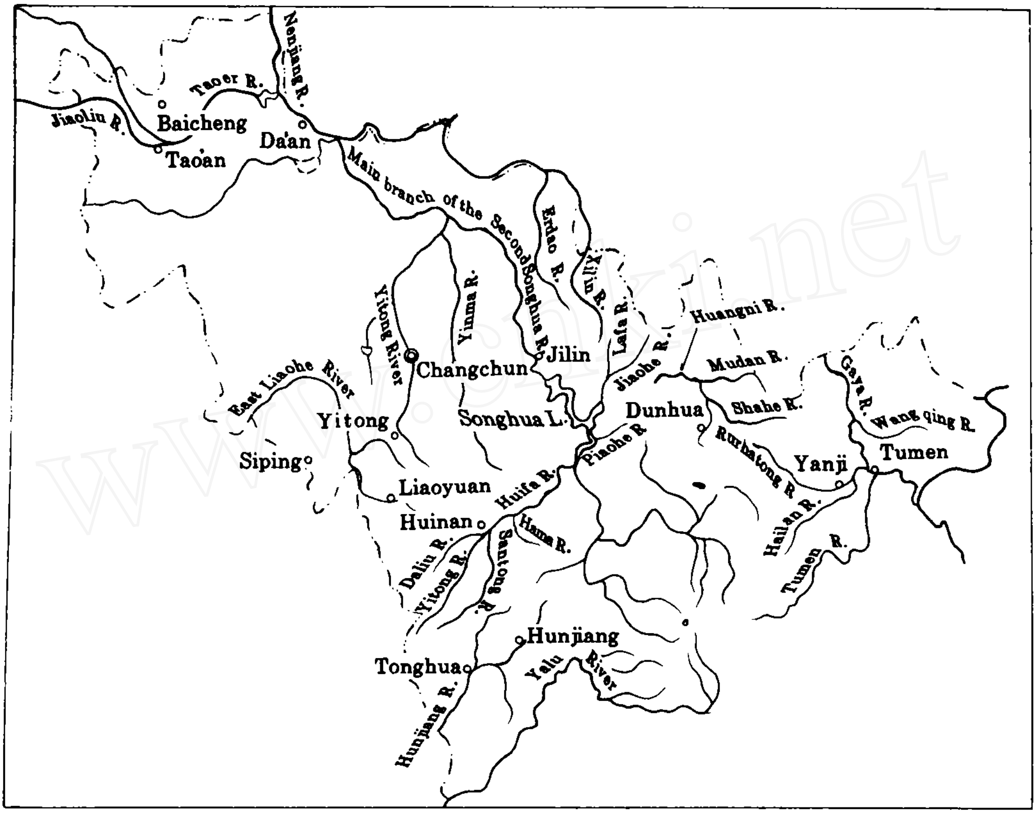

Fig.1 The river system in Jilin Province

BOD_5 reflects most in the first principal component, its correlation coefficient is high enough to 0.9728; then, strongly reflecting Ar–OH, non–ion ammonia, SS and COD, its coefficient is above 0.7;and total hardness; CN and As clearly reflected. Other indexes do not change greatly or monitored rates were low. Pb was reflected in the second principal component, its correlation coefficient is −0.7680. The third principal component reflected NO_2−N and Cr(vi), the fourth principal component reflected pH, the fifth NO_3−N, the sixth DO, and all of their correlation coefficients were over 0.8, Using six principal componentdescribing original sample group, can reflect 86.4% of the total sample group information.

2. Cluster Analysis

System cluster analysis with principal component, repeatedly try in calculation, the most distance method was employed in clustering.

If cutset of $\lambda=3$ level is applied, 27 samples are divided into 9 categories, main two categories and other seven categories.

The first category is composed of 11 samples, the common feature in the category is, belonging to the series of the Second Songhua River and the Suifen River, Ar–OH, COD, SS and non–ion ammonia are the principal pollutants, over standard times is below 1, but Ar–OH in the main branch of the Second Songhua River, water quality is better. The second category is the Huifa River, affected by Huinan County, principal pollutants are COD and BOD_5 the water quality is worse. The third category is composed of 8 samples, series of the Yinma River, the main branch of the Hunjiang River, the Tumen River and the Nenjiang River, the common feature in the category is organic pollution, principal pollutants are SS and COD, the Ar–OH is over standard 15 times in the Yinma River, the water quality is worse. The fourth category is the main branch of the Tumen River, being affected by Kaishantun Chemical Fibre Plant and Maoshan Iron Mine of Korea, the principal pollutant is SS, which is over standard 26 times, COD is over standard near 4 times, BOD_5 and Ar–OH are all over standard, the water quality is very worse. The fifth category have 2 samples, belonging to series of the Lafa River, being affected by the region of Hulan and Yushu, the principal pollutants are nitrogen pollutant, non–ion ammonia, and NO_2–N, over standard 3–4 times, being worse water quality. The sixth category is the series of the East Liaohe River, sand content is big. It is affected by pollutant discharge from Liaoyuan and Siping region, principal pollutants are Ar–OH and SS, which are over standard 9 times, then BOD_5 which is over standard near 8 times, the water quality is very worse. The seventh category is the main branch of the Yalu River, non–ion ammonia is over standard, others are not, the water quality is better. The eighth category is the Yitong River, being affected by Changchun city, principal pollutant is Ar–OH, which is over standard 100 times, then BOD_5 , which over 12 times, the water quality is the worst. The ninth category is the Gaya River, being affected by the Shixian Paper Plant, principal pollutant is organic pollutant, SS is over standard 9 times, COD is over standard 4 times, then BOD_5 and Ar–OH are also over standard, the water quality is very worse. The above classifying is at level of– $\lambda=3$; if $\lambda=5$, the above 9 categories change into 6 categories; if $\lambda=6.9$ all of the samples are in one category.

III. WATER QUALITY ASSESSMENT OF RIVERS IN JILIN PROVINCE

Generally, the following substances as main function in water environment should be chosen: big pollution quantity, high concentration, powerful toxicity, easy accumulation in environment, human body and living being, big economic loss, in order to reflect objectively conditions of water environment quality. Based on principal component analysis result of water quality in Jilin Province, chosen 6 indexes for important assessment indexes are SS, COD, BOD_5, non–ion ammonia, NO_2–N and Ar–OH National GB3838–88, Environment Quality Standard of Surface Water, is chosen (see Table 1).

Table 1 The standard of environmental quality of surface water

Index	I	II	III	IV	V
SS	15	20	25	40	50
COD	2	4	6	8	10
BOD_5	below 3	3	4	6	10
NH_4–N	0.02	0.02	0.02	0.2	0.2
NO_2–N	0.08	0.1	0.15	1.0	1.0
Ar–OH	0.02	0.02	0.05	0.01	0.1

1. Synthetic Index Method

Chosen method is equal–standard index and synthetic index method, combined with over–standard and collecting over–standard index method. Calculation model is for equal standard and synthetic index is:

$$Ii = \frac{Ci}{Cio} \qquad M = \frac{1}{n} \vee \; Ii$$

where *Ii*: single equal standard index for a pollutant

Gi:determined statistics value of concentration for a pollutant (mg/ L)

Cio:assessing standard concentration for a pollutant (mg/ L)

M:synthetic equal standard index

N:assessment item number

(see GB3838–88, III class standard)

Water quality classifying is in Table 2, assessment result is in Table 3.

Table 2 water quality classifying standard for surface water

M Value	Category of water quality
0.2	I. Clean
0.21–0.40	II. Nearly clean
0.41–1.00	III. Light pollution
1.01–2.00	IV. Serious pollution
2.00	V. Very serious pollution

Table 3 Comparison and conclusion of each assessment method

River	Method			Conclusion of synthetic balance
	Synthetic index	Fuzzy math.	Grey correlation	
1. Main branch of the Second Songhua River	IV	IV– V	IV	IV
2. Huifa River	IV	V	IV– V	V
3. Piaohe River	I	I	II	I
4. Lafa River	III	III	II	III
5. Yinma River	V	V	V	V
6. Santong River	III	III	III	III
7. Yitong River	IV	V	IV	V
8. Jiaohe River	III	II	II	II
9. Hama River	IV	V	IV	IV
10. Yitong River	V	V	V	V
11. Daliu River	IV	V	IV	IV
12. Main branch of Tumen River	V	V	V	V
13. Gaya River	V	V	V	V
14. Buerhatong River	III	II	II	II
15. Hailan River	IV	V	V	V
16. Wangqing River	III	III– IV	II	III
17. Mudan River	IV	IV	V	IV
18. Shahe River	IV	V	V	V
19. Huangni River	III	III	II	III
20. Main branch of Yalu River	V	IV	IV	IV
21. Main branch of Nenjiang River	III	IV	III	III
22. Main branch of len River	V	V	V	V
23. Jiaoliu River	V	V	V	V
24. Toudao River	V	V	V	V
25. Erdao River	IV	IV	IV	IV
26. Xilin River	V	V	V	V
27. East Liaohe River				

2. Fuzzy Mathematical Method

Fuzzy synthetic assessment model is used to evaluate the water quality of rivers in Jilin Province, the mathematical form is as follows[3]: six items of pollution item number are selected as evaluating factors, surface water quality is divided into five levels, each standard value is S_1, S_2, S_3, S_4 and S_5, each single factor set is U = (SS, COD, BOD_5, non–ion ammonia, NO_x–N and Ar–OH), surface water quality classifying set is V = (I, II, III, IV, V category).

Based on surface water quality level standard, GB 3838–88, formula of belonging function is selected for each level.

$$r_{i1}=\begin{cases}1 & x\leqslant S_i\\ -\frac{1}{2}(x-S_2) & S_1<x<S_2\\ 0 & x\geqslant S_2\end{cases}$$

$$r_{i2}=\begin{cases}\frac{1}{2}(x-S_1) & S_1<x<S_2\\ -\frac{1}{2}(x-S_3) & S_2<x<S_3\\ 0 & x\leqslant S_1, x\geqslant S_3\end{cases}$$

$$r_{i3}=\begin{cases}\frac{1}{2}(x-S_2) & S_2<x<S_3\\ -\frac{1}{2}(x-S_4) & S_3<x<S_4\\ 0 & x\leqslant S_2, x\geqslant S_4\end{cases}$$

$$r_{i4}=\begin{cases}\frac{1}{2}(x-S_3) & S_3<x<S_4\\ \frac{1}{2}(x-S_5) & S_4<x<S_5\\ 0 & x\leqslant S_1, x\geqslant S_4\end{cases}$$

$$r_{i5}=\begin{cases}1 & x\geqslant S_5\\ \frac{1}{2}(x-S_4) & S_4<x<S_5\\ 0 & x\leqslant S_1, x\geqslant S_4\end{cases}\qquad i=1,2,3,4,5.$$

Above formula is employed for every standard value from big to small, determining weight of every factor in synthetic assessment. Orderly calculating the subordination of each factor to water quality in every class, orderly lining and composing a fuzzy matrix with 6×5, $R=(r_{ij})6\times 5\ (0\leqslant r_{ij}\leqslant 1)$

$$W=Ci\,/\,Si$$

where Ci: monitered value of a pollutant

Si: surface water quality standard of a pollutant

$$Si=1/\ 5(S1+S2+S3+S4+S5)$$

method of mean single weight

$$Wi=(Ci/\ Si)/\ \sum(Ci/\ Si)$$

then, composing a 1×6 matrix $A=(W1\ \ W2......W6)$

After each assessing and weighting, fuzzy matrix of A and R was obtained. Y was obtained by calculating A and R . After obtained Y, the category is most subordination in most subordination rule, and is the category of synthetic assessment. Based on the rule of most subordination, water quality of 6 pollution factors synthetic assessment of every river in Jilin Province is in Table 3.

3. Grey Correlation Analysis Method

Grey correlation method is used for water quality synthetic assessment[4,5], describing mainly with the order of correlation; assessed sample of water is placed in relevant water quality on most correlation.

Level standard of water quality and water sample are of a grey system.

$$U=U(i),\ (i=0,\ 1,\ 2,\ 3,\ 4,\ 5)$$

where $i=0$ describing water sample; $i=1,2,3,4,5$ describing level standard of water quality, I, II, III, IV and V category.

$[Xi(k)]$ stand for the value of k pollutant target in water sample and water quality standard in classifying, $i=0,1,2,3,4,5$; $k=1,2,3,4,5,6$. Data sequence of water quality sample is called reference sequence

$$[X(k)]=[X(1),\ X(2),\ ......X(6)]$$

Data sequence of level standard of water quality is called compared data sequence:

$$[Xi(k)]=[Xi(1),\ Xi(2),\ ...\ Xi(6)],\ (i=1,2,3,4,5)$$

defining

$$\triangle i(k) = X(k) - Xi(k), \ (i = 1,2,3,4,5)$$

As absolute difference of*X*with *Xi*in corresponding target, correlation coefficient is calculated by following formula:

$$\zeta_{i(k)} = \frac{\min_i \min_k |X_0(k) - X_i(k)|}{|X_0(k) - X_i(k)|} \cdot \frac{+\rho \max_i \max_k |X_0(k) - X_i(k)|}{+\rho \max_i \max_k |X_0(k) - X_i(k)|}$$

where ρ is called differentiating coefficient, a figure between 0 and 1, generally select 0.5.

Last, calculate correlation of compared number sequence $[Xi(k)]$, (i = 1,2,3,4,5) with reference number sequence $[X_0(k)]$

$$r_i = \frac{1}{6} \sum_{k-1} \zeta_{i(k)}$$

Then, obtaining the correlation, ri (i= 1,2,3,4,5), of water quality classifying standard sample with assessed water sample should be assessed as water quality of No *i*category. Calculation result is in Table 3.

4. Assessment Result Analysis

Each assessment result of river water quality in Jilin Province is compared, and determined the conclusion of synthetic equilibrium, see Table 3.

4.1 Rivers are polluted at different degree in Jilin Province

In assessment, more serious polluted rivers make up 44.4% of all rivers, serious polluted rivers make up 25.9%, light polluted rivers make up 18.5%. Based on water quality synthetic pollution index, the sequence of more serious polluted 5 rivers are the Yitong River, the East Liaohe River, the main branch of the Tumen River, the Yinma River and the Gaya River(tributary of the Tumen River). The rivers with better quality are the Piaohe River, the Jiaohe River, the Buerhatong River and the main branch of the Yalu River.

4.2 More polluted waters in Jilin Province are river sections through cities and towns

Principal pollutants are organic compounds; the rivers with over SS standard are 81.48% in monitored rivers in Jilin Province, COD 62.96% and BOD 33.33%.

The most serious polluted rivers is the Yitong River, the annual average concentration of Ar–Oh being 0.8 mg/ L, over standard 163 times, BOD_5 at 12 times, non–ion ammonia at 9 times, COD at 7. The second order in synthetic polluted degree is the East Liaohe River, SS and Ar–OH being over standard 8 times, BOD_5 and COD 8 times. The most serious SS polluted is in the main branch of the Tumen River, the annual average concentration of 684 mg/ L over standard 26.4 times, COD and BOD_5 are also over standard. The principal pollutant is Ar–OH in the Yinma River, the annual mean concentration is 0.08 mg/ L, over standard 15 times, COD and BOD_5 are also over standard. The SS in the Gaya River is over standard 9 times, COD, Ae–OH and BOD_5 are also over standard.

The light polluted is the Piaohe River, every pollutant is not over the standard; the Jiaohe River and the main branch of the Yalu River only have a little high concentration of non–ion ammonia, others not; in the Buhatong River, only SS is over standard, others not.

As for The main branch of the Second Songhua River, synthetic pollution degree is in 12 place, belonging to serious polluted water section; the principal pollutants: Ar–OH is over standard 2.4 times, SS 0.8 times, and COD 0.5.

4.3 The main reason of water being serious polluted in Jilin Province

The main reason causing serious water pollution in Jilin Province is thedischarge of industrial and domestic wastewater. The rivers passing through cities and towns were more serious polluted than its upper and lower reaches. The organic compounds pollution shows big difference between different river sections, dozen times and even a hundred times. The natural conditions are mainly affected by seasonal rainfall and runoff, generally, greatly affected in dry season, and lightly in plenty reason. Each pollutant is mainly diluted for making water quality better. There are no effective pollution–control measures for river water quality, producing the situation of discharging industrial and domestic wastewater, so increasing polluting water resource and rivers through cities and towns.

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