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A STUDY ON QUALITY OF AQUATIC ENVIRONMENT IN TUMEN RIVER AREA①

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ABSTRACT: After the survey of pollution sources, a study on surface water quality assessment and forecast is given by means of grey system method, fuzzy mathematical method and multiple-index method. Based on it, aquatic environment quality features, treatment measures and environmental strategies of the area are proposed. The quality of aquatic environment of 5 rivers in the Tumen River area is studied. The results show that the pollution of surface water is serious; water quality of most rivers is between grade IV and V except the Hunchun River, being higher than grade IV standard; pollution levels of most rivers have been basically controlled except the of Burhatong River, which is deteriorating gradually. Pollutants of the rivers are comparatively regular, mainly are SS, COD, BOD, AR-OH, NH_3-N. The main pollution trades are chemical fibre industry, pulp and paper making industry and mining industry. If the growth rate of gross industrial product is higher than 25 percent under the encouraging-model of regional exploitation, the pollutants' load will overtake the bearing capacity of aquatic environment. Thus some protection program against pollution must be worked out in order to achieve the harmonious development of economy society and environment.

KEY WORDS: pollution sources, aquatic environment quality, environmental forecast, Tumen River

With the raising of the issues of development of the Tumen River Delta, the Tumen River area catches comprehensive attention of international society and becomes one of the study focuses. The paper here is trying to study and discuss the problems of surface water quality and aquatic environment quality by using modern techniques and considering the exploitation of this area.

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I. GENERAL SITUATION

The Tumen River is a boundary river between China and Korea. The Tumen River area studied in the paper includes Hunchun, Tumen, Yanji and Longjing cities in China side, it is about 10 102.4 km^2. The mutual tangential crossing between latitudinal structural system and Neocathaysinan structural system forms the basic framework of geologic structure in the area and shows the geomorphologic feature of more mountains and less plains. The area belongs to temperate-frigid zone with continental subhumid monsoon climate, it has over five frozen months in one year, its average humidity is about 68%. Average annual precipitation varies from 397 mm to 847mm. The Tumen River originated in the east slope of the main peak of the Changbai Mountains. Because of its large gradient ratio of river bed and flowing along faulted zone, the current flows torrentially and the incision of the river is very strong. The span of the river is 505.4 km, the main tributaries are the Gaya River, Burhatong River, Hailan River and Hunchun River. The annual run off variation coefficients of each river are in the range of 0.40 – 0.53. Influenced by the climate, precipitation is mainly concentrated in summer and the runoff volumes of each river vary largely in each year. In summer there are often high flood peaks while the spring floods' crests are not so high. All these streams have a long frozen period.

According to the statistics by the end of 1993, the population of the area is 943 000, the distribution of population is very uneven. By the end of 1993, the gross social product is 9 297.7 million yuan (RMB); gross industrial product is 5 265.5 million yuan, making up 56.6 percent of gross social product; the ratio of gross agricultural product is comparatively small. the density of product is 920 300 yuan/km^2, that of Yanji City is the highest, Longjing City the lowest.

II. THE PRESENT AQUATIC ENVIRONMENTAL QUALITY OF SURFACE WATER IN TUMEN RIVER AREA

1. General Situation of Pollution Sources

By the end of 1993, the total discharge volume of waste water is 100 370 000 tons in the studied area, among which industrial waste water is 72 780 000 tons. In recent years, the discharge of industrial waste water shows the growing trend while the total volume of discharge is declining. The rate of waste water treatment and the rate of meeting the standard are comparative low but show the growing trend. The main pollutants discharged by waste water sources are COD, SS, BOD, AR-OH, CN, As, Cr^{6+}, Pb and oils, the most is COD, SS and BOD_5 take the second place.

According to the monitoring data of waste water sources in Yanji, Hunchun, Tumen and Longjing cities by environmental protection administrative departments, the comprehensive assessments are made respectively by years, administrative regions and enterprises by means of equistandard pollutant loading, the results show that the Tumen River area is mainly polluted by chemical fibre industry, main enterprises with pollution source of waste water are Kaishantun Chemical Fibre Plant and Shixian Paper Making Plant. Main pollutants discharged are COD, SS and BOD_5.

2. Factor Analysis of Regional Aquatic Environmental Quality

The monitoring data of aquatic quality on seven chosen environmental indexes (COD, SS, BOD_5, AR-OH etc.) of 18 sections in the Tumen River system in 1993 were studied by means of factor analysis. Through the coefficient matrix of these seven indexes, we evaluated the eigenvalue: 2.360, 2.067, 1.329, 0.655, 0.388, 0.195, 0.007 (the first three public factor covered 82 percent of original information), the varimax rotated factor matrix (see Table 1) and factor scores for each section (see Table 2). The first three factor present three combina-

Table 1 Factor loadings

Environmental Index	F_1	F_2	F_3
SS	- 0.079	0.469	0.703
COD	0.915	- 0.010	0.380
BOD_5	0.876	0.266	0.219
NH_3- N	0.070	0.884	- 0.225
NO_2- N	0.084	0.611	- 0.595
AR- OH	0.754	0.032	- 0.422

Table 2 Factor scores

Sections	F_1	F_2	F_3
Chongshan	- 0.894	- 0.922	0.308
Nanping	- 1.097	1.795	1.987
Tumen	0.937	0.23	1.833
Hedong	0.374	0.82	0.382
Quanhe	- 0.011	0.06	- 0.519
Biyan	- 0.353	- 0.12	- 1.307
Dongshengqiao	1.943	- 0.289	- 0.892
Helong	1.064	- 0.089	- 1.693
Zhuanchang	- 0.823	0.298	- 0.673
Henanqiao	0.073	2.454	- 1.093
Xidong	- 0.611	1.119	- 0.558
Sandao	- 0.670	- 0.941	0.135
Xiaga	2.253	- 0.345	1.332
Baye	0.624	- 0.573	0.331
Chunhua	- 0.729	- 1.288	0.217
Daqiao	- 0.727	- 0.926	0.121
Sanjiazi	- 0.679	- 0.505	0.035
Xiwaizi	- 0.677	- 0.784	0.003

tions of different environmental indexes: F_1 mainly presents organic pollutants' (COD, BOD_5, AR-OH etc.) indexes; F_2 presents pollutants' indexes of nitrogen compounds (NH_3-N, NO_3-N); F_3 presents that of SS. Table 2 shows that Xiaga, Dongsheng, and Helong sections etc. with higher scores in F_1 are mainly polluted by organic pollutants; those sections such as Nanping, Congshan and sections of Hunchun River with lower scores in F_1 are mainly polluted by oxygen compounds; Tumen and Nanping sections with high scores in F_3 are mainly polluted by suspended matter. It also shows that the surface water environment in the Tumen River area are seriously polluted, a few of sections are clean. The types of pollution are organic pollution, nitrogen pollution and suspended pollution. The pollution types of five rivers in the area are: the Tumen River, organic pollution; the Burhatong River, nitrogen pollution; the Gaya River, suspended & organic pollution; the Hunchun River, suspended pollution.

3. Assessment of Present Aquatic Environment Situation

3.1 Methods of assessment

In order to prevent from the deviation caused by single method of assessment and come to a more objective and reasonable conclusion, the methods of equistandard pollution capacity, multiple-index (averaged index M_1, weighted index M_2, robust index M_3), fuzzy mathematics (Zhu *et al*., 1985) and grey related analysis (Deng, 1985) are chosen to synthetically assess the chosen eight environmental indexes of SS, DO, COD, BOD_5, NH_3-N, NO_2-N, NO_3-N, AR-OH (DO is excluded in the method of equistandard pollution capacity). "the Quality Criteria of Ground Water" GB3838-88 is taken as the standards of evaluation; and "the Quality Criteria of Songhua River System" (temporary) (from grade I to V, the criteria are 15, 20, 25, 40, 50 mg/l) is used in assessing SS.

3.2 Assessment of present aquatic environment situation

By using the methods mentioned, the annual means of aquatic monitoring data of 18 sections of the Tumen River system in 1993 are synthetically evaluated and a comprehensive conclusion is presented after comparing the results of each method (see Table 3 and Table 4).

The results in the tables show that surface water in the Tumen River area is seriously polluted except the Hunchun River, which is slightly polluted. The water quality of the upper reaches and the middle reaches is superior to that of the lower reaches of each river. Among the 18 sections being assessed, the worst water quality is Naping (mainly polluted by SS), Henanqiao and Hedong sections, the best is Chunhua section. The main pollutants are NH_3-N, SS, COD, AR-OH in eight evaluation indexes.

In order to reveal the seasonal features of aquatic quality of environment in the area, we also synthetically evaluated the water quality monitoring data of recent years in each sections in mainstream of the Tumen River, Gaya River, Burhatong River and Hunchun River by wet period, median water period and low water period. The result shows that the quality of most water bodies during wet period and median water period is superior to that of low water period,

Table 3 Result of status of water quality assessment by means of equistandard pollution capacity method

Rivers	Sections	SS	COD	BOD_5	NH_3-N	NO_2-N	NO_3-N	AR-OH	Total
Mainstream of Tumen River	Chongshan	0.40	0.63	0.21	3.00	0.00	0.02	0.00	4.25
	Nanping	49.64	1.73	0.34	23.40	0.19	0.04	0.00	75.35
	Tumen	25.58	6.99	3.32	3.90	0.14	0.02	1.20	41.15
	Hedong	14.70	4.40	2.30	28.05	0.23	0.02	1.00	50.69
	Quanhe	6.56	2.69	0.85	1.95	0.29	0.02	4.60	16.95
	Total	96.88	16.44	7.01	60.30	0.86	0.11	6.80	
Hunchun River	Chunhua	0.16	0.75	0.29	0.00	0.01	0.00	1.21	
	Daqiao	1.76	0.80	0.30	0.20	0.05	0.01	0.80	3.93
	Sanjiazi	2.36	1.06	0.41	0.30	0.12	0.02	1.80	6.06
	Xiwaizi	2.20	0.91	0.29	0.20	0.09	0.02	1.40	5.10
	Total	6.48	3.52	1.29	0.70	0.25	0.06	4.00	
Gaya River	Sandao	3.12	0.83	0.47	3.50	0.06	0.01	0.00	6.98
	Xiaga	4.24	9.93	1.96	7.00	0.05	0.01	4.60	30.78
	Baye	3.28	4.77	2.17	4.00	0.11	0.01	3.00	17.34
	Total	10.64	15.52	7.60	14.50	0.22	0.03	7.60	
Burhatong River	Zhuanchang	0.39	0.60	0.66	6.50	0.32	0.03	0.00	8.49
	Henanqiao	1.12	1.05	2.68	59.50	0.31	0.04	4.40	69.09
	Xidong	0.80	0.79	1.40	30.50	0.27	0.03	0.40	34.19
	Total	2.31	2.45	4.73	96.50	0.89	0.10	4.80	
Hailan River	Biyan	0.52	0.83	0.77	12.50	0.35	0.00	0.40	15.40
	Dong-shengqiao	1.48	6.16	2.57	14.00	0.19	0.00	12.80	37.20
	Helong	1.52	3.42	1.48	13.00	0.36	0.00	9.80	29.58
	Total	3.52	10.41	1.81	39.50	0.93	0.00	23.00	

Table 4 Comparison of various evaluation methods

Section	Multiple-index method				Fuzzy mathematics method	Grey related analysis method	Synthetical conclusion
	M_1 method	M_2 method	M_3 method	Composite within terms			
Chongshan	II	II	II	II	I	I	I
Nanping	V	V	V	V	V	II	V
Tumen	V	V	V	V	V	II	V
Hedong	V	V	V	V	V	II	V
Quanhe	IV	IV	IV	IV	V	II	IV
Biyan	IV	IV	IV	IV	V	I	IV
Dongshengqiao	V	V	V	V	V	IV	V
Helong	V	V	V	V	V	IV	V
Zhuanchang	IV	IV	III	IV	I	I	I
Henanqiao	V	V	V	V	V	III	V
Xidong	V	V	V	V	V	II	V
Sandao	IV	IV	III	IV	V	II	IV
Xiaga	V	V	V	V	V	II	V
Baye	IV	IV	IV	IV	V	V	V
Chunhua	I	I	I	I	I	I	I
Daqiao	II	II	II	II	I	II	II
Sanjiazi	III	III	III	III	V	II	III
Xiwaizi	III	II	II	II	V	II	II

it is because the pollution types of most sections are organic pollution and nitrogen pollution, in wet and median water period the runoff strengthens, in the meantime the temperature is higher than that in low water period, all these factors facilitated the growth of aquatic organisms so that the dilution and biodegradation of geochemistry in regional aquatic environment strengthen too. As for the Hunchun River and Gaya River, the water quality in low water period is superior to that in wet and median water period, this is because the pollution types of the two rivers are mainly suspended pollution, in the period of low water the water volume is small and the water flows slowly, and this favored to the deposition of SS.

III. THE FORECAST OF AQUATIC ENVIRONMENT QUALITY OF TUMEN RIVER AREA

Many models are applied in the studies of environmental sciences, and grey system model GM(1, 1) is one of the preferable models. According to the water quality monitoring data in 18 sections of five rivers from 1986– 1993, the values of M_1, M_2 and M_3 could be evaluated by means of multiple-index method, then the grey model of action GM(1, 1) and GAM(1, 1) could be built up on the data and passed the posterior difference test, after that we can forecast the water quality of the area by using these models (see Table 5). According to the result of forecasting, the surface water quality of the area will be controlled basically, the pollution of most sections show the declining trend, the water quality of the area will be improved to a certain degree by the year 2010. Of course this forecast is on the basis of the hypothesis of economy, society, and environment by changing situation of nature at present time. But the

Table 5 Forecast of aquatic environmental quality in Tumen River

River	Section	Forecasted year			Variation trend of pollution
		2000	2005	2010	
Mainstream of Tumen River	Chongshan	I	I	I	Decrease
	Nanping	V	V	V	Increase
	Tumen	V	V	IV	Decrease
	Hedong	V	V	IV	Decrease
	Quanhe	IV	IV	III	Decrease
Gaya River	Sandao	I	I	I	Decrease
	Xaiga	I	I	I	Decrease
	Baye	I	I	I	Decrease
Burhatong River	Zhuanchang	V	V	V	Increase
	Henanqiao	V	V	V	Increase
	Xidong	V	V	V	Increase
Hailanhe River	Biyan	II	I	I	Decrease
	Dongshengqiao	IV	IV	III	Decrease
	Helong	IV	III	II	Decrease
Hunqun River	Chunhua	I	I	I	Decrease
	Daqiao	I	I	I	Decrease
	Sanjiazi	II	I	I	Decrease
	Xiwaizi	II	I	I	Decrease

Burhatong River is a river of which the water quality is deteriorating in the region.

IV. THE FORECAST OF AQUATIC ENVIRONMENTAL QUALITY OF THE REGION UNDER THE ENCOURAGING-MODEL OF DEVELOPMENT

1. Relationship between Social Economy and Quality of Aquatic Environment

The raising of the theories of sustainable development in the 1980s not only renovated the conception of traditional development of human social economy fundamentally, but also brought a fundamental reformation on environmental strategy. In order to forecast the environmental quality reasonably, we should firstly discuss the relationship between aquatic environmental quality and regional social economy.

Because the effect on aquatic environmental quality of regional social economy displayed on water quality of the mainstream of the Tumen River comprehensively, we first should evaluate the water quality of each section of the mainstream of the Tumen River by the means of multiple-index method and then weight the value according to the distance from each section to the source of the river. The weighted value of the nearer section should be smaller than that of the farther. After that the indexes of water quality of the whole mainstream of the Tumen River could be evaluated (Table 6).

Table 6 Regional social economy and aquatic environmental quality in main stream of Tumen River

Year	Population (person)	Gross social product (× 10^4 yuan)	Gross industrial product (× 10^4 yuan)	Total volume of waste water (× 10^4 t)	Industrial waste (× 10^4 t)	Indexes of water quality		
						M_1	M_2	M_3
1986	812923	196613	165514	11796	7260	13.1	13.8	10.6
1987	834456	277508	207778	11646	7431	5.22	5.29	4.68
1988	812923	370347	232799	11499	8121	7.00	7.38	5.81
1989	876763	420302	260834	11353	8298	8.74	9.35	6.71
1990	860037	448752	355278	10766	8346	7.06	7.58	5.37
1991	894682	493770	374239	11327	8874	3.42	3.50	2.67
1992	917600	630772	442349	10483	8515	6.36	6.65	5.33
1993	942975	929770	526550	10037	7278	4.67	4.88	3.70

2. The Forecast of Aquatic Environmental Quality under the Encouraging-Model of Development

To forecast the water quality of the area under the encouraging-model by adopting system cooperative forecast technology (Wang *et al.*, 1991), at first variables are set according to Table 6: X_1: index of water quality, X_2: total volume of waste water, X_3: industrial waste,

X_4: population, X_5: gross social product, X_6: gross industrial product. In order to efface the influence between quantitative grades, the original data are initialized first, then grey models are built by each factor.

From Table 6 and integrated with the grey related analyses on indexes of water and each index of social economy in the table, we concluded that the present comprehensive water quality of the mainstream of the Tumen River was in the level of grade Ⅴ, but with the growth of gross social product and gross industry product, aquatic environmental quality would be basically controlled, it means that the developing of regional economy coordinated with the changing of environment on the whole, it also stated that the study by using system cooperative technique was feasible.

(1) Water quality indexes and GM(1, 6) model on them by total volume of waste water, industrial waste, population, gross social product and gross industrial product.

$$x = a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 + a_{15}x_5 + a_{16}x_6$$

through calculating, $a_{11} = -2.2178$, $a_{12} = -20.6406$, $a_{13} = -1.5391$,
$a_{14} = 27.3046$, $a_{15} = -0.7410$, $a_{16} = -2.6260$.

(2) Total waste water and GM(1, 3) model on it by total industrial waste and population.

$$\dot{x} = a_{22}x_2 + a_{23}x_3 + a_{24}x_4$$

through calculating, $a_{22} = -5.4607$, $a_{23} = 4.9652$, $a_{24} = -0.4723$.

(3) Industrial waste and GM(1, 2) model on it by gross industrial product.

$$\dot{x} = a_{33}x_3 + a_{36}x_6$$

through calculating, $a_{33} = -0.9829$, $a_{36} = -0.4679$.

(4) Population and its GM(1, 1) model

$$\dot{x} = a_{44}x_4 + u_4$$

through calculating, $a_{44} = 0.0226$, $u_4 = 0.9730$.

(5) Gross social product and GM(1, 2) model on it by gross industrial product.

$$\dot{x} = a_{55}x_5 + a_{56}x_6$$

through calculating, $a_{55} = -0.9209$, $a_{56} = 1.2675$.

(6) Gross industrial and its GM(1, 1) model

$$\dot{x} = a_{66}x_6 + u_6$$

through calculating, $a_{66} = 0.1578$, $u_6 = 0.9720$

With each coefficient of above grey model groups, we get structural coefficient matrix A and u_0 of conditional equations.

Ta
$$A = \begin{pmatrix} -2.2178 & -20.6406 & -1.5391 & 27.3047 & -0.7410 & -2.6260 \\ 0 & -5.4607 & 4.9652 & -0.4723 & 0 & 0 \\ 0 & 0 & 0.9829 & -0.4679 & 0 & 0 \\ 0 & 0 & 0 & 0.0226 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.9209 & 1.2675 \\ 0 & 0 & 0 & 0 & 0 & 0.1578 \end{pmatrix}$$

$$u = (0, 0, 0, 0, 973, 0, 0.972)^{T}$$

First we evaluated the above equations by means of Rung-Kutta method, then returned the values to original by accumulative minus and reinitializing, after that we got each simulative value and forecasting value, at last offered the level of grade of water quality by these values. As for regional development of the Tumen River region, the influences of international investment and domestic special policies will course the overspeeding developing of economy necessarily. The developing coefficient of gross industrial product of the region is 15.78 percent from 1986 to 1993, given the existence of encouraging mechanism, it was replace by the growth rate of 15.78%, 20%, 25% and 30% respectively in structural matrix A when water quality of the region was forecasted. The result could be seen in Table 7 (Because the relationship between gross social product and gross industrial product was already included in the structural matrix, their increase was also included in the discuss).

Table 7 Result of the system cooperative forecast

Growth rate of gross industrial (%)	Forecasted years		
	2000	2005	2010
15.78	IV	IV	III
20	V	IV	IV
25	V	V	V
30	V	V	V

The forecast in Table 7 shows that under the encouraging-model at the present environmental protection level, the pollutant load will surpass the bearing capacity of aquatic environment of the region when the growth rate is over 25% (the contribution to the pollution of the Tumen River by industrial growth of Korea is out of consideration). Only a growing rate under 20% is comparative appropriate. It should be pointed out that in the Tumen River region, the development is of greatest importance, our purpose of forecast is not try to decrease the pollution by limiting producing. The purpose of ecological environmental control is to combine pollution control with development of economy. This requires minimizing new pollution and recovering or improving the polluted environment in the meantime of developing economy by the combination of carrying out of cleaning producing technology, treating of pollution terminals and transforming of abandoned sources.

V. CONCLUSION

(1) The pollution of surface water in the Tumen River region is serious, the water quality levels of most river sections are in grade IV or V level, only that of the Hunchun River is superior to grade III. Most rivers are under controling except the Burhatong river, of which the water quality presents the trend of descending.

(2) Main pollutants are relatively fixing, they are mainly SS, COD, BOD, AR-OH, NH_3-N etc. The pollution types of each section could be summarized as suspended pollution,

organic pollution and nitrogen pollution. The main pollution trades are chemical fibre industry, paper making industry and mining industry.

(3) Under the encouraging-model of regional development, when the growth rate surpass 25%, the pollutant loading will go beyond the bearing capacity of aquatic environment. In order to coordinate the development of economy, social and environment, a corresponding policy of environmental protection should be made in the meantime of constituting the developing strategies of the region.

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