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THE FLUX OF LAND-BASED SOURCE POLLUTANTS FROM TUMEN RIVER SYSTEM ENTERING THE SEA OF JAPAN①

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ABSTRACT: The influence of land-based source pollutants to marine ecological environment is principally in coastal or enclosed sea waters. Flux of land-based source pollutants into the sea will be effected due to social and economic development in the Tumen River basin. Pollutant type and primary pollution factor of the Tumen River in Northeast China is described by weighted coefficient method in this paper. The results indicate that the river is organic pollution type and primary pollution factor is COD. Fresh water fraction proves that the estuary is not affected by tide cycle. COD annual flux entering the Sea of Japan calculated by zero-dimension model in 1993 was 90.50×10^3 tons. It is estimated with emission coefficient method that the COD will be 176.4×10^3 and 458.6×10^3 tons for the years of 2000 and 2010 respectively.
KEY WORDS: Tumen River, COD, the Sea of Japan, pollution forecast, land-based source pollutants, marine pollution

I. INTRODUCTION

"Agenda 21" recognizes the importance of land-based source pollutants to marine pollution. Coastal water is of great significance for biological productivity and bio-diversity. It has an important sense to the economy and ecology, too. The water carried pollutants entering the sea from point and nonpoint sources contribute to 44 of all ways (UNEP, 1992). The influence of land-based source pollutants to marine ecological environment is principally in coastal or enclosed sea waters. Flux of land-based source pollutants into the sea will be effected due to social and economic development in the Tumen River basin. Therefore, it is necessary to judge pollution type and its primary pollution factor of the Tumen River system. We also calculate and forecast annual flux of the years, 2000 and 2010.

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II. THE TUMEN RIVER SYSTEM AND ITS ESTUARY FEATURE

1. The Tumen River System

The Tumen River system consists of the Burhatong River, the Hailan River, the Gaya River, the Hunchun River, the Wangqing River and the Tumen River. In addition, there are also small branches directly entering the Tumen River or the above rivers. Quanhe Hydrographic Station is the closest monitoring site to the estuary.

2. The Estuary Feature

The sketch map of the Tumen River estuary is shown in Fig. 1.

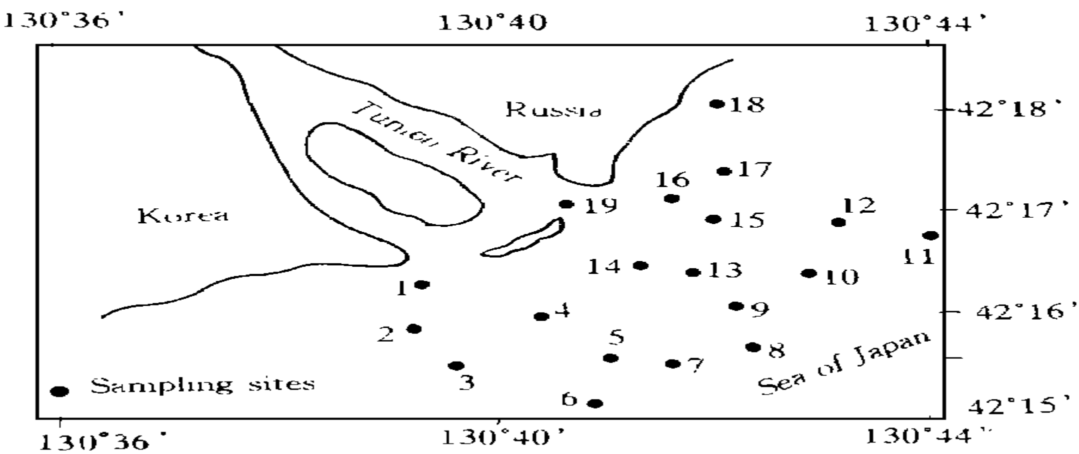

Fig. 1 Sketch map of Tumen River estuary

Tide cycle of the estuary is an important factor to judge the capacity of the pollutants transfer and to decide the flux of land-based pollutants flowing into the sea. Freshwater fraction can determine whether the estuary has a tide cycle. Mathematical expression is:

$$F = (S_s - S_i) / S_s \quad (1)$$

where: F is freshwater fraction, i.e. the percentage of freshwater in total water of estuary; S_s is salinity of local freshwater outside estuary (‰); S_i is average salinity of river water inside the estuary (‰).

Salinity for different sites inside and outside the Tumen River estuary is listed in Table 1.

Table 1 Measured values of salinity of sampling sites 1– 19 (Zhang, 1992)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Salinity (‰)	31.8	32.5	32.5	31.8	33.3	32.7	/	/	/	/	/	/	32.2	14.3	33.3	33.3	33.3	33.1	0.0

The salinity of site 14 and site 19 are 14. 3 and 0 respectively. Other sites have almost same salinity of sea water. It has known that freshwater flow from site 19 toward site 14 (see Fig. 1). According to the expression (1), S_s is sea water salinity and salinity of S_i is 0. Therefore F value equals to 100%. The feature of the estuary is not effected by tide cycle. In this case, the river reach (40 km) from Quanhe Hydrographic Station to the site 19 should be regarded as an inland river.

III. POLLUTION TYPE AND ITS PRIMARY POLLUTION FACTOR

There are a variety of pollution type in surface water and there are many environmental pollution factors in different pollution types. Self-purification capacity of different environmental pollution factors is different and the emission by human activities is also different. Therefore, they have obvious regional characteristics. Pollution type and its primary factor in river water can be determined with weighting coefficient method (Ye, 1989). This method includes contributions of frequency exceed acceptable standard and pollution intensity. Because we use actual measured data for calculation, the arbitrary conclusion is avoided.. Its mathematical expression is as follows:

$$W_i = 1/2(A_i / \sum A_i + B_i / \sum B_i)$$

$$\sum W_i = 1 \qquad (2)$$

where W_i is pollution factors, A_i is the average of frequency which exceed acceptable standard for assessment pollutants i for many monitoring measurements. ΣA_i is the accumulation of all A_i, B_i is a ratio of monitoring average to acceptable standard for pollutant i. ΣB_i is accumulation of all B_i.

According to the monitoring data (selected for only the pollutant factors exceeding acceptable standards) of Quanhe Hydrographic Station, W_i values calculated using the expression (2) are listed in Table 2.

Table 2 Calculated results of pollution factors

	SS	COD	BOD	NH_4- N	Phenol	Pb
W_i	0. 14	0. 41	0. 13	0. 093	0. 197	0. 031

W_i values in Table 2 show that COD_{mn} is a primary pollution factor. Evidently belongs to organic pollution type.

IV. DETERMINATION OF POLLUTION INDICATORS AND CALCULATION OF K_1

1. The Regression Equation

BOD_5 is usually used as an indicator of physical and biochemical process in water quality model due to dilution and degradation of pollutants. It is an important index of oxygen balance. However primary pollution factor in the Tumen River is COD_{mn}. In compliance with correlation analysis a simple linear regression equation between COD_{mn} and BOD_5 can be made in order to calculate COD_{mn} flux entering the Sea of Japan.

According to monitoring data of Quanhe Station during plentiful, normal and low water periods from 1990 to1994, a simple linear regression equation is made:

$$COD_{mn} = 4.771 + 3.306\, BOD_5$$

$$r = 0.9614 \qquad n = 10 \tag{3}$$

The relationship between COD_{mn} and BOD in the Tumen River has a very good correlation.

2. Calculation of Oxygen Consumption Coefficient K_1

The process of oxygen consumption for BOD consists of two stages. The first stage conducts carbonization of oxygen consuming organism during the first 7– 20 days when temperature is 20 ℃. The second stage is nitrification that is a very slow process. The carbonization is a major stage effecting river water quality. So K_1 value can be calculated with two-point method of Rhamede in the laboratory(Ye, 1989; Fu *et al.*, 1985). The mathematical equation is as follows:

$$K_1 = 1/(T - t) * \ln(X/Z - X) \tag{4}$$

K_1 is a measurement value at 20℃ in laboratory. Since K_1 is a function of temperature, the mathematical expression is as follows:

$$K_1(T_c ℃) = K_1(20 ℃) * 1.047(T_c - 20) \tag{5}$$

In the expression (4), T_c is time (2 t (10 d); t is time (5d); X is the value of BOD_5; Z is the value of BOD_{10}. In the expression (5) T_c is average water temperature (℃) during the year. Annual average temperature in the river is 9.2 ℃.

The samples collected in winter of 1994 were analyzed to determine BOD_5 and BOD_{10} in the laboratory, and the K_1 under different temperatures were calculated by the equation (4) and (5). The results is listed in Table 3

Table 3 Calculated results of K_1

BOD_5	BOD_{10}	K_1(20℃)	K_1(9.2℃)
22.26	28.68	0.2487	0.1516

V. DEGRADATION OF POLLUTANTS

During the process of pollutant entering the sea via rivers and / or pipelines, there is a corresponding decrease of pollutants owing to the diffusion, dilution, degradation and volatilization. In our study, the degradation is considered as the primary process.

1. Selection of Model

Since there is no change of tide cycle in the estuary, we can regard the 40 km river reach as an inland river and divide it into m small units with a length ΔX. Thus, each small unit could be regarded as one complete mixture reactor and the 40 km river reach to be consist of a series of m complete mixture reactor. It is assumed that there is not any other source and leakage in this reach the reactions of pollutants is the first order dynamic reaction. The concentration of pollutants can be calculated by zero dimension model (Fu *et al.*, 1985). The model is:

$$V * dc/dt = Q(C_0 - C) - k_1 CV$$

Under a steady state condition, it can be simplified into:

$$C_m = C_{m-1}/(1 + k_1 * \triangle x / u)_m \quad (6)$$

where C_m is pollutant concentration of the m small unit of the river stage (mg/l);

k_1 is a constant of the first order dynamic reaction rate;

$\triangle x$ is the length of small unit (m);

$\bar{u}$ is the average flow velocity in the 40 km river reach (m/s); when $m = 1$, C_{m-1} equals to C_0, i.e. the pollutant concentration of starting profile.

Regard annual average of BOD_5 at Quanhe Station as BOD_5 concentration of starting profile, average of BOD_5 was annually 3.49 mg/l in 1993.

2. The Calculation of the COD Concentration at River-sea Interface

The river width from Quanhe Station to the site 24 is on an average 3 times as large as the width of Quanhe Station. The average hydrographic parameters provided by hydrological station of Yanbian Korean Autonomous Region are employed to calculate the annual average flow velocity. It is 0.22 m/s, and the annual average runoff volume is 71.81×10^9 m^3.

The 40 km river reach is divided into 80 small units and each unit is 0.5 km. The BOD_5 concentrations in all small units can be calculated by equation (6). In our study, the term $(1 + K_1 * (\triangle x / u)$ in equation (6) is a constant, the equation (6) then can be simplified into:

$$C_m = C_{m-1}/1.0013 \qquad m = 1, 2, \ldots\ldots, 81.$$

$$C_0 = 3.49. \quad (7)$$

The calculation shows that in each small unit the BOD_5 concentration is decreased by 0.014 mg/L. Total decrease in the whole reach is 1.12 mg/l. Therefore, BOD_5 concentration at the site 24 is 2.37 mg/l. The concentration of COD entering the Sea of Japan calculated would be 12.61 mg/L.

3. The Flux of COD Entering the Sea of Japan in 1993

The mathematical expression of the flux is as follows:

$$Q_{COD} = C_{COD} * q_w / 10^6 \quad (8)$$

where Q_{COD} is the annual flux of COD entering the Sea of Japan (t) ;

C_{COD} is the annual average concentration of COD entering the Sea of Japan (mg/ L) ;

q_w is the annual average runoff volume in many years (m^3) .

With expression (8), the flux of CDO can be calculated as 905.0×10^3 tons. It should be pointed that this datum includes the emission from in northarn part of Korea and background COD concentration.

VI. FORECAST

1. COD Emission

On the assumption that natural conditions, industrial structure, environmental technique, investment , production processes remain constant and no accidents take place, the pollutant emission will be almost in proportion to the economic and population growth. According to the planning of the four cities, the total COD emission can be forecasted with the emission coefficient method taking 1993 as the base year. The results is shown in Table 4.

Table 4 The forecast of population, gross value of industrial output and COD emission

		Yanji	Tumen	Hunchun	Longjing	Total
Population	2000	27. 13	7. 40	12. 25P	8. 71	55. 49
($\times 10^4$)	2010	30. 0	8. 02	13.4	9. 63	61. 05
COD emission coefficient of domestic sewage (t/a• p)		0. 04283	0. 03271	0.01068	0. 01173	0. 02449
Gross value of industrial	2000	276658	181652	230577	108490	797357
output ($\times 10^4$ yuan)	2010	1220460	515785	1258818	213416	3208479
COD emission coefficient of industrial wastewater (t/ 10^4 yuan)		0. 005082	0. 425506	0. 092623	0. 0842656	0. 267905
Sewage COD_{mn}	2000	11619. 8	2420. 5	1308. 3	1021. 7	16370. 3
emission (t)	2010	12849. 0	2623. 3	1431. 1	1129. 6	18033. 0
Industrial wastewater	2000	1406. 0	77293. 8	2135. 8	91419. 8	191474. 5
COD_{mn} emission (t)	2010	6202. 4	219469. 8	116600. 5	179836. 6	522109. 3
Total COD_{mn} emission	2000					207845
from four cities (t)	2010					540142

Total COD emission from four cities makes up 71. 22 percent of the river system

2. Forecast of Flux of COD Entering the Sea of Japan

The flux of land-based source pollutants entering the sea is associate with its emission closely. The expression is:

$$Q = \sum (a_i, b_i, c_i, \ldots)\ q \tag{9}$$

where Q is the flux of pollutants entering the sea;

$a_i, b_i, c_i, \ldots$ are coefficients which associate with emission of pollutant i and less than 1;

q is the emission of pollutant i.

If COD is considered only, equation (9) can be changed into equation (10).

$$Q = \sum a_i * q$$

$$\sum a_i = Q / q \tag{10}$$

Total COD emission for four cities contribute 71.22 percent of the river system.

According to the COD emission and the flux of COD entering the Sea of Japan in 1993 $\sum a_i$ is calculated as 0.6047 by equation (10).

The forecast results of COD annual flux entering the Sea of Japan are listed in Table 5.

Table 5 The results of forecast

Objective year	COD emission in the region ($\times 10^3$ t)	The flux of COD entering the sea in the region ($\times 10^3$ t)
2000	291.8	1764
2010	758.4	4586

VII. CONCLUSION

The pollution of the Tumen River is organic pollution type. Its major pollution factor is COD. The estuary of the Tumen River is not effected by tide cycle. The 40 km river reach from Quanhe Station to site 24 can be considered as an inland river. The annual flux of COD entering the Sea of Japan was 905.0×10^3 tons in 1993.

The COD annual flux of land-based sources COD entering the Sea of Japan is forecasted. They are 1764×10^3 tons in 2000 and 4586×10^3 tons in 2010 respectively.

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