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Characteristic Analysis and Loss Accounting for Water Pollution in Plain River Network Region - A Case Study of the Yangtze Delta

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Abstract. Because there are many water systems, severe human activities, increasingly serious water pollution problems and great economic loss in the plain river network region, the establishment of scientific and reasonable economic loss function is necessary to guide the protection and management of water resources. Taking the Yangtze Delta as an example, the characteristics of water pollution in the same period are that the flood season is stronger than the non-flood season. The analysis based on the physical mechanism shows that the process of economic loss of water pollution not only accords with S-type curve but also gives a reason for the S-type curve from the aspect of mechanism. The water pollution loss rate function which is constructed on the basis of hyperbolic tangent function divides the development stage into such three stages as non-enrichment, enrichment and saturation of pollutants, gives turning points of each stage as well as the solution and significance of parameters and enriches the physical process of models. The results of living samples show that the comprehensive water grades can be obtained easily and quickly through the river length failure rate. Their good correlation has certain promotion significance. The total water pollution economic loss is bigger. The average economic loss in the flood period from May to July is bigger than that in the flood period from August to September and non-flood period. The living samples prove that there exists pollutant diffusion phenomenon in the flood period.

1. Introduction

With the rapid development of social economy, industrialization and urbanization, increasingly serious water pollution problem in China resulted in huge economic losses ^[1], which became one of China's core water problems and restricted the economic and social sustainable development ^[2], especially in the plain river network region. Because of serious water pollution, deteriorative water environment and dangerous water ecological safety, the pollution-induced water shortage has become the main form of water shortage in such region ^[3]. According to statistics, the economic loss on industry, agriculture, municipal engineering, human health and others which is caused by water pollution is as high as about 240 billion RMB per year. Therefore, to establish a clear and simple accounting technology for the economic loss of water pollution, which can describe the damage degree of water pollution directly and clearly, it is necessary to guide the conservation and management of water resources.

The Yangtze Delta is located in the lower reaches of the Yangtze River, with a large number of waterways and dense water conservancy projects like polders and gate dams, so the Yangtze Delta is characteristic of strong manual scheduling, poor self-purification capacity and complex hydraulic



linkage^[4], which is the features of a typical plain river network region. The economy in the region developed rapidly after the 1980s. From then on, water pollution intensified year by year and water environmental problems are increasingly prominent^[5]. Therefore, this paper, taking the Yangtze delta as an example, analyzes the mechanism process of water pollution loss in this region on the basis of water pollution which evolves with hydrological process and establishes a water pollution economic loss model with physical mechanism for the calculation of water pollution loss.

2. Water pollution characteristics in plain river network region in the Yangtze Delta

2.1. Selection of characteristic variables

As the commonly used index for the surface water quality evaluation of rivers, the river length compliance rate can reflect water quality in the river network to some extent. Considering the inverse relationship between compliance rate and water quality category, the river length failure rate is introduced to analyse the relationship between the river length compliance rate and river length failure rate. The river length failure rate W_i is put forward in comparison with the river length compliance rate W_i' , its statistical unit is in month and its calculation formula is shown as below.

$$W_i = 1 - W_i' \quad (i = I, II, \dots, V) \quad (1)$$

The relationship between the monthly comprehensive category Q of the water quality in the river network in the Yangtze Delta from 2001 to 2012 and the river length failure rate W is shown in Fig 1, the correlation coefficient R is 0.71 and the error range e is $[-0.5, +0.4]$ which is within allowable range, so the river length failure rate can be chosen as a characteristic variable describing the surface water quality.

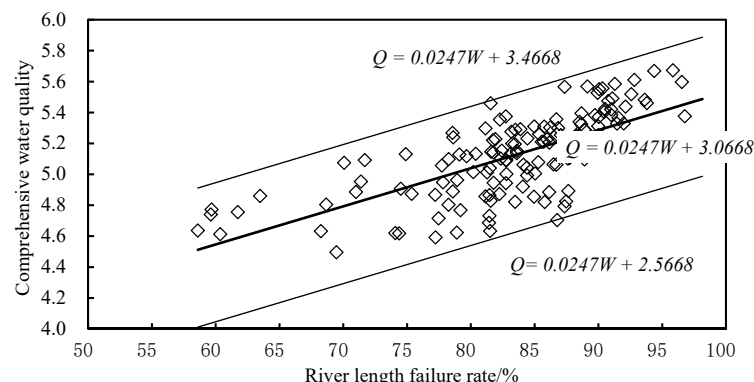


Figure 1. Correlation between proportion of pollution of river length and comprehensive water quality

2.2. Analysis of water pollution evolution situation in the river network

The Yangtze Delta region belongs to subtropical monsoon climate, the annual mean precipitation is 1147.7mm, of which about 60% occurs in the flood period from May to September. The hot and rainy summers with frequent precipitation has a profound impact on the situation of water pollution, therefore, it is very necessary to study the water pollution change process with the accumulative precipitation. The change process (Fig. 2) of monthly river network failure rate from 2001 to 2012 with the accumulative precipitation shows that there is an obvious peak point in July (at the place of ▲) each year. The failure rate of river network increases in the early stage while decreases in the latter stage. Therefore, the evolution situation of water pollution is discussed through dealing the stages of flood period and non-flood region.

The flood period of the Yangtze Delta is from May to September. According to the precipitation statistics, the average cumulative precipitation in May, July and September from 2001 to 2012 was 405mm, 758mm and 1014mm, respectively. After studying the correlation between cumulative precipitation and the river length failure rate, the annual average flood period and non-flood period are divided on the basis of the mean accumulative precipitation from May to September. As shown in Fig.

3, the solid line is the boundary of the flood period, the dashed line is the mean accumulative precipitation of the turning point in July. The law that the river length failure rate in non-flood period changes with the increase of accumulative precipitation is not obvious, so it can be treated as general normality. The river length failure rate in the flood period from May to September is slightly higher. In addition, the river length failure rate from May to July increases with the increase of accumulative precipitation, which indicates the water pollution become serious. However, the river length failure rate from July to September decreases with the increase of accumulative precipitation, which indicates water pollution decreases. As a result, the water pollution in flood period in the Yangtze delta season has several different stages, that is to say, the rain and pollution occur at the same period. The evolution of water pollution from 2001 to 2012 is characterized as follow: 1) the river length failure rate in the Yangtze Delta keeps more than 50% all year round, especially in the flood period, it will remain more than 70%, the pollution is very serious; 2) the pollutant transfer has obvious segmentation in flood period, and the cumulative precipitation ($p=758\text{mm}$) in July is the boundary line of segmentation. Therefore, the water pollution in the Yangtze delta is characterized by the diffusion of pollutants in the pre-flood period and the dilution of pollutants during the later flood period, and more serious pollution during the flood period. To this end, the whole year is divided into flood period, dilution period and non-flood period to capture the water pollution loss in the Yangtze delta

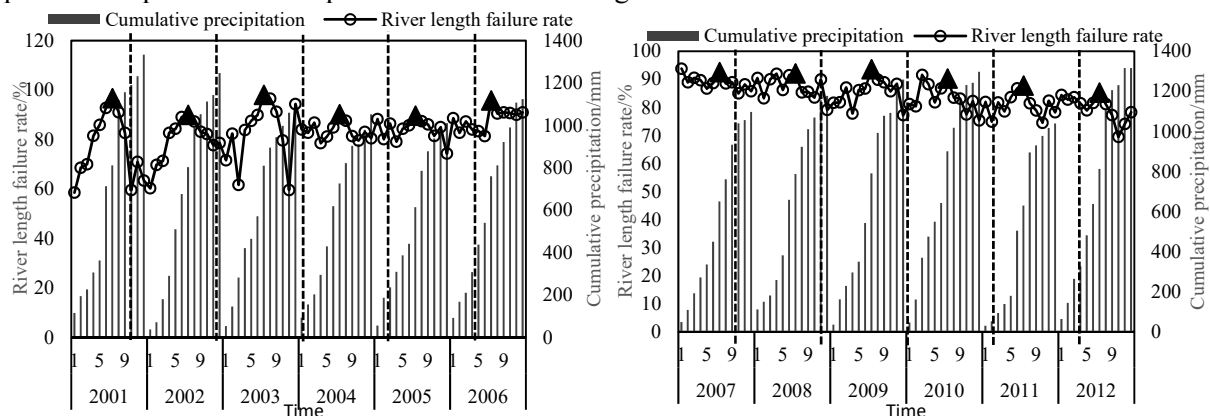


Figure 2. The process of the proportion of pollution of river length with cumulative rainfall from 2001-2012

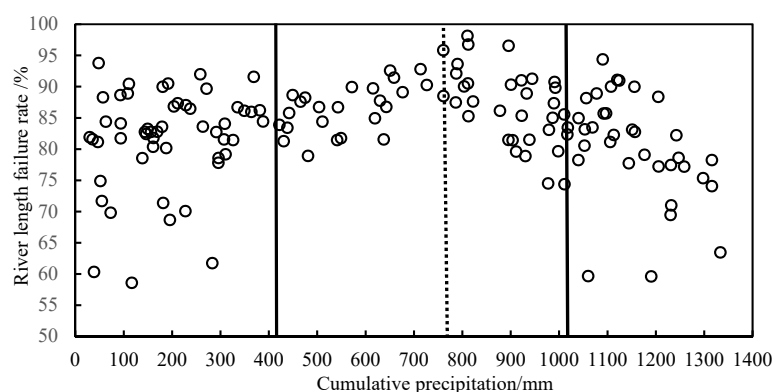


Figure 3. The regulation of the proportion of pollution of river length with cumulative rainfall

2.3. Description of mechanism

The Yangtze Delta is located at the mouth of the Yangtze River, which has the characteristic of flat terrain, small gradient, poor hydrodynamic conditions and slow flow rate. Some studies^[6] show when the water velocity is less than 0.5m/s , the river's hydrodynamic ability to handle pollutants is weak^[7]. The water flow rate in the part of the river network in the Yangtze Delta is only 0.1m/s , some are even in a stationary state, thus resulting in a large number of pollutant depositions, which form sewage mass

that can become a new pollutant source under the action of the rectilinear water current. A large number of flood control projects, gate dams, polders and other water conservancy projects separate the water body within the dams from the outside river channels^[8] and the hydraulic connection was cut off, so the characteristics of the channel segmentation is significant. The pollution control of water conservancy facilities like gate dams in non-flood period make industrial and domestic sewage gather together in some part of the river, the sewage masses contaminate the water body in the form of new pollutant sources. In the flood period, the precipitation carries these pollutants into the river network. With the increase of water quantity, the pollutant receiving capacity of water body is increasing, the self-purification capacity of water body is improved as well, the pollutants in water body are degraded gradually, thus alleviating water pollution.

3. Water pollution loss function

3.1. General description of water pollution loss

Water disaster loss can be described by vulnerability curve. It represents the relationship curve between the disaster of different intensity and loss. Chen Minqian^[9] explained water disaster process from the aspect of the process of the accumulation and release of more general quantities and energy. They considered that the start and development of water disaster are due to the growth of quantity and energy, and when the energy accumulates to a certain extent, it will be released; at the same time, it is a common phenomenon that there always exists an impedance force during the development process of event. So the process of quantity and energy accumulation is a non-linear growth as a result of impedance effect. In the initial stage, if the driving force is suspended or weakened due to its own reasons, the accumulated energy is stopped by the impedance, the accumulating process of energy almost comes to an end. If the driving force is not reduced, the energy can be accumulated continuously, the accumulated energy will be released after breaking through the impedance, thus there will be explosive development. Finally, as the energy is released, the decay phase begins and the event subsides due to the impedance effect. Therefore, the increase curve of water disaster loss takes the shape of S.

Water pollution is the phenomenon of water quality deterioration that the reason for the change of the physical, chemical, biological and other characteristics of water body. Considering from the complete event of water pollution, the change of water quality category from Grade I to worse Grade V is a gradual process with a beginning and an end. In the course of the event, the self-purification capacity of water body always plays an important role in hindering the deterioration of the water quality. With the constant input of pollutants, the pollution is escalating. When the deterioration of the water quality reaches to a certain extent, the pollutants are saturated, and the basic service function is lost for the water body, thus the disaster event ends. Under the action of water self-purification capacity, pollution treatment and other impedances, pollutant enrichment is hindered, showing the growth of gentle enrichment or non-enrichment. With the increase of pollutant amount, the self-purification capacity of water body can only hinder the enrichment of some pollutants, at this time, the enrichment process begins to accelerate and the enrichment quantity increases constantly. When the amount of pollutants exceeds the self-purification capacity of water body, the water body loses the effective impedance to the pollutant enrichment, the enrichment quantity increases rapidly. When the enrichment quantity is close to saturation, the enrichment process is subjected to the impedance again and the event ends gradually. According to the similar theories, the whole process of pollutant enrichment is similar to that of energy accumulation in physics, the process of water pollution disaster conforms to S-shaped curve, the corresponding economic loss rate also shows the same trend, as shown in Fig. 4, and the general formula of loss function shown as the follow Formula.

$$f(Q) = \frac{K_i}{2} \left(\frac{e^{2\alpha(Q-Q_B)} - 1}{e^{2\alpha(Q-Q_B)} + 1} + 1 \right) \quad (2)$$

Q is the comprehensive water grades of water body, α is vulnerability coefficient and A is the undetermined coefficient, K_i is the maximum loss rate.

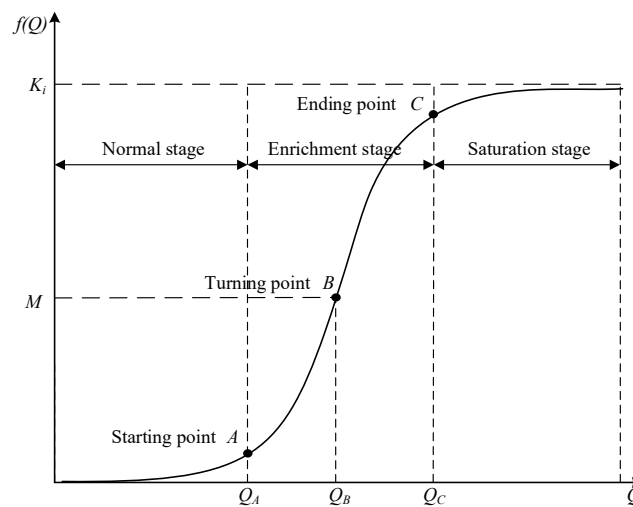


Figure 4. The curve of the function of water pollution loss

3.2. Solution and significance of parameters

3.2.1. Maximum loss rate K_i . Maximum loss rate K_i is defined as the proportion of the maximum economic loss caused by water pollution disaster to economic aggregate. It can be obtained by substituting the survey data of the economic loss of the typical units in the study area into the function of economic loss rate of water pollution.

3.2.2. Vulnerability coefficient α . Vulnerability coefficient is determined according to the ability of water itself to resist water pollution. The larger vulnerability coefficient is, the more possible pollution loss is. According to the first derivative $\frac{df}{dQ} = 2\alpha \cdot \frac{e^{2\alpha(Q-Q_B)}}{(e^{2\alpha(Q-Q_B)} + 1)^2} \cdot K_i$, the steep degree of the curve is determined by the degree of vulnerability coefficient. If α is larger, the curve is steeper.

3.2.3. Critical points Q_A , Q_B and Q_C . Q_A , Q_B and Q_C are the turning points of the curve. Point B is the inflection point of the curve, where the smoothness of the curve changes. Point A is central symmetrical to point C about point B, which meet the equations of $Q_A = Q_B - \frac{0.66}{\alpha}$ and $Q_C = Q_B + \frac{0.66}{\alpha}$. Therefore, if any two points of A, B and C are known, the another point and the value of α can be obtained.

4. Calculation of economic loss caused by the water pollution in the Yangtze delta

The economic loss caused by water pollution is calculated according to the S-typed water pollution economic loss rate curve. As a typical plain river network region, the noticeable characteristic of the water pollution in the Yangtze Delta is that the rain and waste water occurs over the same period. In the loss accounting, comparative proof is achieved by sectional calculation.

4.1. Value of parameters

4.1.1. Maximum loss rate K_i . The K_i in the economic loss function reflects the largest economic loss rate in each industry when water pollution is most serious. Water pollution mainly has an influence on agriculture, industry, municipal engineering, tourism, household consumption, human health and other

aspects. Based on the current results, K_i is modified in combination with the characteristics of the Yangtze Delta, the maximum loss rate K_i of the water pollution in the benchmark year 2011 is shown in Table 1.

Table 1. The value of K_i caused by water pollution

Category	K_i (2011)	Unit	Remark
Agriculture (farming, fisheries and animal husbandry)	0.45	RMB/a	Price levels converted from 1998 to 2011
Industry	Electronic industry	0.05	
	food service industry	0.06	
	General industry	0.013	
Municipal industry	Waterworks	0.6	
	sewage disposal work	1.26	
tourism income		0.1	RMB/a
household consumption		181	RMB/(capita.a)
health damage		485	RMB/(capita.a)

4.1.2. α 、 Q_A 、 Q_B 、 Q_C . The surface water grade is divided into 6 grades from Grade I to worse than Grade V, so the comprehensive water grades are set as $Q \subseteq [1, 6]$. The vulnerability coefficient and water pollution loss rate of sub-industries are obtained through the value of the characteristic points by using the S-typed water pollution economic loss rate curve. Combined with relevant studies^[10], $Q_B=4$ is set at inflection point B, $Q_C=6$ is set at stop-loss point C, obtaining $Q_A=2$ and $\alpha=0.33$, then the expression the water pollution economic loss rate and total loss function of the water in the river network in the Yangtze Delta is:

$$f_i(Q) = \frac{K_i}{2} \left(\frac{e^{0.66(Q-Q_B)} - 1}{e^{0.66(Q-Q_B)} + 1} + 1 \right) \quad (3)$$

$$Z = \sum_{i=1}^n f_i(Q) \cdot F_i \quad (4)$$

Z is the total economic loss for the water pollution, including such three periods as diffusion stage from May to July, dilution stage from August to September and non-flood period. $f_i(Q)$ is the loss rate of corresponding industry, F_i is the total economic value of corresponding industry.

4.2. Accounting of water pollution loss

Above analysis, the water pollution economic loss is calculated through three time intervals. Monthly water pollution economic loss rate $f_i(Q_j)$ and the economic loss of sub-items is obtained by substituting monthly comprehensive water grade into the above function. With price level in 2011 as the benchmark, the economic losses in the three stages are counted, as shown in Table 2. The total economic loss from 2001 to 2012 which was caused by water pollution is larger, until 2012 the economic loss decreased greatly. Compared with economic aggregate, the proportion of the total economic loss was decreasing year by year. Nevertheless, the total economic loss is still one of the main loss types of water disaster in the Yangtze delta.

Table 2. The economic loss in flood and dry season from 2001 to 2012 unit: 100 million

Year	May to July		August to September		Non-flood period		total loss	percentage
	total loss	Monthly average loss	total loss	Monthly average loss	total loss	Monthly average loss		
2001	86.38	28.79	55.44	27.72	182.07	26.01	323.9	5.10%
2002	94.19	31.4	59.06	29.53	208.88	29.84	362.12	5.02%
2003	97.01	32.34	65.82	32.91	214.79	30.68	377.62	4.22%

2004	103.71	34.57	65.26	32.63	230.23	32.89	399.2	3.56%
2005	116.75	38.92	73.01	36.51	258.44	36.92	448.2	3.36%
2006	112.78	37.59	78.03	39.02	265.13	37.88	455.94	2.95%
2007	126.46	42.15	82.56	41.28	286.04	40.86	495.06	2.76%
2008	132.61	44.2	86.34	43.17	304.43	43.49	523.38	2.55%
2009	130.84	43.61	85.43	42.71	295.38	42.2	511.66	2.42%
2010	138.72	46.24	89.59	44.79	313.63	44.8	541.93	2.18%
2011	139.62	46.54	86.15	43.08	319.06	45.58	544.83	1.94%
2012	119.87	39.96	75.56	37.78	273.06	39.01	468.5	1.58%

5. Conclusion

The water pollution in the plain river network region is serious all the year round and there is rain water and waste water over the same period in the stages of diffusion and dilution during flood period, so the economic loss caused by water pollution should be divided into such three stages as the diffusion and dilution in the flood period and non-flood period.

The economic loss caused by water pollution is counted with loss rate as a dependent variable and comprehensive water grade as an independent variable. Its evolution process conforms to the development trend of the S-typed curve for the accumulation and release of general energy. In the process of calculation, the economic loss is generalized to hyperbolic tangent function, and it is divided into three stages (non-enrichment, enrichment and saturation) by the enrichment degree of pollutants. The physical process is clear and the significance of relevant parameters are more explicit. The living examples of the economic loss caused by water pollution prove that the water pollution in the Yangtze Delta is very serious, and there is the diffusion phenomenon of pollutants in flood period and rain water and waste water over the same period that the water pollution in the flood period is more severe than that in the non-flood period.

The calculation of economic loss caused by water pollution only considers the visible physical loss value, so the result is smaller. In the application study in other regions, the accounting contents can be increased according to the actual management needs and different emphases in order to better guide the protection and management of water resources.

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