Research on the method of responsibility division of transboundary water pollution

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Abstract. With the rapid development of China's economy and society, there has been a serious crisis in the field of water environment safety. Due to the mobility of water and the spatial distribution of water in the basin and other reasons, cross-border water pollution has become a major issue of general concern to the state and the whole society. In this paper, the scope of responsibility of pollutants is generated using the one-dimensional steady-state water quality dynamics based on the basic data of the target area, the corresponding basic data of water quality, water quantity, administrative scope and responsible person so on, so as to realize the comprehensive responsibility division of water quality of cross-border water bodies. The pollutant attenuation coefficient was used to calculate the pollution concentration of pollutants from the initial section of the upstream of the responsibility jurisdiction to the section of the river section at the end of the jurisdiction, which can avoid the calculation error caused by the concentration changes of the pollutants under the comprehensive effects of hydrology, hydraulics, chemistry, physics, geography, biochemistry, climate, location and meteorology in the process of transportation, and improve the accuracy of pollution liability definition of each administrative area.

1. Introduction

China is facing a grave transboundary water pollution problem with serious social and economic harm in the upstream and downstream areas of the water basin. All kinds of shocking transboundary water pollution accidents are constantly being reported, stirring up a heated discussion among the public. For example, the Songhua River water pollution caused by the explosion at a petrochemical plant in Jilin province in 2005 almost triggered a conflict between China and Russia[2]. For this reason, President Xi paid close attention to water pollution and made an investigation in Jilin province in recent days. In addition, recently, the Ministry of Ecological Environment and the Ministry of Water Resources jointly issued the "Guidance on the Establishment of a Joint Prevention and Control Mechanism for Water
Pollution Emergencies in the Upstream and Downstream of Transprovincial River Basins", which clearly states that the monitoring and early warning capabilities of water pollution emergencies must be enhanced.

At present, some scholars have analyzed the causes for transboundary river pollution. Extensive economic growth mode, unreasonable water environment management system and lack of water pollution prevention and control system are the three major causes. Once the transboundary river pollution occurs, the impact between an individual and an integral whole in different regions will become complex. Most provinces in China have further introduced ecological compensation methods on the basis of assessing the transboundary river section, and corresponding economic compensation is provided according to water quality assessment results. However, the ecological compensation is mostly carried out according to the ranking of surface water quality, ignoring the error caused by changes of pollutant concentration due to the transportation of pollutants along the river flows[3]. The main pollutants causing transboundary river pollution are ammonia nitrogen, total phosphorus (TP), organic pollutants and heavy metals[4].

Using a single factor analysis method and a comprehensive factor analysis method, combining with one-dimensional water quality dynamics model, this paper compared and analyzed the water quality changes of the river basin under the jurisdiction of all levels of river governors, determined the corresponding water quality changes when rivers flow into their destination and differences between all types of water qualities, and provided the water dispatch guidance for river chiefs.

2. Responsibility Division for Transboundary Water Pollution

After pollutants enter a river, they will travel along with river flows and the concentration will change. The time it takes to change the concentration mainly depends on the nature of pollutants and the reduction of pollutants by the river. The pollutant reduction system reflects the results of the comprehensive effects of hydrology, hydraulics, chemistry, physics, geography, biochemistry, climate, location, and meteorology during the transportation of pollutants. The reduction coefficient of pollutants in the river is also affected by their own stability, particle sizes, water depths, velocity, roughness and slope[5]. There are many pollutants in rivers with complex properties, but the concentrations of COD, ammonia nitrogen, and TP are commonly used to determine the pollutant content in each river basin[6].

For the middle and small river sections where the pollutants can be mixed evenly on the cross section, a one-dimensional constant water flow quality model is used to simulate the process in which pollutants do not travel along the longitudinal direction of the river section. The formula for calculating the pollutant concentration after pollutants flow through river section L is as follows:

\[ C_L = C_0 \exp \left(-k \frac{L}{u}\right) \]  

(1)

Where \( C_L \) is the quality concentration of pollutants at the end of river section L (mg·L⁻¹); \( C_0 \) is the quality concentration of pollutants at the beginning of river section L; K is the comprehensive reduction coefficient of pollutants (s⁻¹ or d⁻¹); u is the average flow velocity at the cross section (m·s⁻¹). In this paper, the empirical formula of "Code of Practice for Computation on Permissible Pollution Bearing Capacity of Water Bodies" (GB/T 25173-2010) and White's empirical formula are used to calculate the comprehensive reduction coefficient of pollutants.

\[ k = 10.3Q^{-0.49} \]  

(2)

Where k is the comprehensive reduction coefficient of pollutants, Q is the river flow (m·s⁻¹).

The mean value of the concentration of each single indicator of all monitored river sections is calculated, the water quality index of each single indicator is calculated, and then the water quality index of the whole river is calculated comprehensively \( CWQI_{River} \),

(1) Water quality index of a single indicator

The water quality index of a single indicator is calculated by dividing the concentration of a single indicator by the limit value of standard III of surface water.
\[ CWQI(i) = \frac{C(i)}{C_w(i)} \]  

(3)

- \( C(i) \) — the concentration value of the \( i \)th indicator
- \( C_w(i) \) — the limit value of standard III of surface water for the \( i \)th indicator
- \( CWQI(i) \) — the water quality index of the \( i \)th indicator

(2) River water quality index

According to the \( CWQI \) of each indicator, the sum value is taken as \( CWQI \) of the whole river.

(3) Responsibility division method:

In this paper, the river responsibility coefficient is introduced to determine the responsibilities of water pollution. For example, the formula for calculating the responsibility coefficient \( \Delta C_{A-B} \) of river section AB is as follows:

\[
\Delta C_{A-B} = \left( \frac{C_B(i) - C_{LA}(i)}{C_{w}(i)} \right) \]  

(4)

Through the collection of water quality and quantity data of relevant river sections, the responsibility of transboundary water pollution is divided and determined. For the main stream, water samples of sections in the upper reaches and lower reaches within each jurisdiction (or administrative region) or water samples at the starting section of administrative jurisdiction are collected. The specific collection methods are applied by referring to the relevant technical requirements of "Technical Specification for Surface Water and Sewage Monitoring" HJ/191-2002. For tributaries, water samples at the starting section of the jurisdiction and water samples at the section where tributaries flow into the main stream are collected.

3. Experiment and Result

3.1. Data Collection and Correction

Figure 1 shows the flow direction of a main river and its branch in a water system in East China. The river flows run from A to B. Now the river has three administrative units. During responsibility division, the river is divided into three sections, which are Section AB, Section BC, and Section CD. Section BC has a tributary river which has a section named Section 12. The total length of the whole river is about 6.5 km with an area of 26.7 km². In recent years, the river water quality has been assessed as the inferior V type for a long time, and the water is black and smelly.

![Figure 1 River division based on administrative regions](image)
point of Section BC, which is also the place to get the water sample of Section CD, and D is the place to get the water sample of Section CD. Among them, there is a tributary in Section BC. We also collected relevant water samples at Section 2-2' of the starting section of the tributary jurisdiction area, and at Section 1-1' where the tributary flows into the main stream. The water quality data is shown in Table 1.

| Water Quality Indicator | Section A-A' | Section B-B' | Section C-C' | Section D-D' | Section 1-1' | Section 2-2' |
|-------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| COD                     | 25.3         | 26.1         | 46.7         | 43.9         | 16.1         | 20.7         |
| Ammonia nitrogen        | 0.52         | 0.89         | 1.77         | 1.58         | 2.1          | 2.7          |
| TP                      | 0.45         | 0.42         | 1.33         | 1.05         | 0.23         | 0.35         |
| CWQI                    | 3.40         | 3.64         | 9.59         | 7.93         | 3.65         | 4.97         |

According to the calculation formula of one-dimensional constant water flow quality model, we corrected the water quality data of river sections, eliminated the error caused by reduction of various pollution indicators, and avoided the deviation of responsibility division. Table 2 shows the corrected water quality data.

| Water Quality Indicator | Section A-A' | Section B-B' | Section C-C' | Section D-D' | Section 1-1' | Section 2-2' |
|-------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| COD                     | 18.89        | 19.48        | 35.12        | 43.90        | 12.64        | 20.70        |
| Ammonia nitrogen        | 0.39         | 0.66         | 1.33         | 1.58         | 1.65         | 2.70         |
| TP                      | 0.34         | 0.31         | 1.00         | 1.05         | 0.18         | 0.35         |
| CWQI                    | 2.54         | 2.72         | 7.21         | 7.93         | 2.87         | 4.97         |

3.2. Division of River Section Responsibilities
The responsibilities of river sections are divided by the river section responsibility index, as shown in the table below. For a single water quality indicator, we use the ratio of the difference in corrected water quality data between the upper and lower reaches to the target water quality to define the pollution responsibility. Once the value is greater than 0, it indicates that the water quality indicator became worse from the upper reaches to the lower reaches, and the higher the value, the greater the contribution it made to the pollution. On the contrary, it indicates that the upper reaches do not have pollution impact on the lower reaches. At the same time, we can also use the comprehensive responsibility index to judge the comprehensive pollution responsibilities.

| Water Quality Indicator | Upper Reaches | Lower Reaches |
|-------------------------|---------------|--------------|
| CWQI                    | CWQI<sub>upstream</sub> | CWQI<sub>downstream</sub> |

\[ \Delta C(i) = \frac{C_{\text{upstream}}(i) - C_{\text{downstream}}(i)}{c_{\text{target}}(i)} \]

\[ C_{\text{upstream}}(i) \text{ is a corrected concentration value of a single water quality indicator of the upper reaches,} \]
\[ C_{\text{downstream}}(i) \text{ is a concentration value of a single water quality indicator of the lower reaches.} \]
$CWQI_{\text{upstream}}$ is a corrected concentration value of a comprehensive water quality indicator of the upper reaches, $CWQI_{\text{downstream}}$ is a concentration value of a comprehensive water quality indicator of the lower reaches.

Table 5 Division of river pollution responsibility for COD indicator

| **Water quality responsibility for COD indicator** |
|-----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **River** | **Section** | **Section AB** | **Section BC** | **Section CD** |
| **Main stream** | Cross-section | A-A' | B-B' | B-B' | C-C' | C-C' | D-D' |
| Before correction | 25.30 | 26.10 | 26.10 | 46.70 | 46.70 | 43.90 |
| After correction | 18.89 | 26.10 | 19.48 | 46.70 | 35.12 | 43.90 |
| **Tributary** | Section (Not flow through this cross-section) | Tributary Section 12 | Section 1-1' | Section 2-2' |
| Before correction | / | 16.10 | 20.70 | / |
| After correction | / | 12.64 | 20.70 | / |

From the above table, the pollution responsibility index calculated by using the original detection data shows that when COD, one of the water quality indicators, travels through Section AB and Section BC, the pollution responsibility index is greater than 0, while on the contrary, the index is less than 0 when COD travels through Section CD, which indicates that this river section does not cause the pollution in the lower reaches. However, the pollution responsibility index of Section CD calculated by using the corrected COD concentration value is 0.22, indicating that this section still made certain contribution to the pollution, that is, Section AB, Section BC, and Section CD all contributed to the pollution in the lower reaches. In addition, Section 12 of the tributary also has a certain impact on the pollution of the entire river. As we can see, Section BC is the main section contributing to the COD pollution of the river, then followed by Section CD and Section AB.

Table 6 Division of river pollution responsibility for ammonia nitrogen indicator

| **Water quality responsibility for ammonia nitrogen indicator** |
|-----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **River** | **Section** | **Section AB** | **Section BC** | **Section CD** |
| **Main stream** | Cross-section | A-A' | B-B' | B-B' | C-C' | C-C' | D-D' |
| Before correction | 0.52 | 0.89 | 1.77 | 1.58 | 2.10 | 2.70 |
| After correction | 0.19 | -0.10 | 0.66 | 1.58 | 1.33 | 2.70 |
| **Tributary** | Section (Not flow through this cross-section) | Tributary Section 12 | Section 1-1' | Section 2-2' |
| Before correction | / | 2.10 | 2.70 | / |
| After correction | / | 1.65 | 2.70 | / |
From the above table, the pollution responsibility index calculated by using the original detection data shows that when ammonia nitrogen, one of the water quality indicators, travels through Section AB and Section CD, the pollution responsibility index is greater than 0, while on the contrary, the index is less than 0 when ammonia nitrogen travels through Section BC, which indicates that this river section does not cause the pollution in the lower reaches. However, the pollution responsibility index of Section BC calculated by using the corrected ammonia nitrogen concentration value is 0.46, indicating that this section still made certain contribution to the pollution, that is, Section AB, Section BC, and Section CD all contributed to the pollution in the lower reaches. In addition, Section 12 of the tributary also has a certain impact on the pollution of the entire river. As we can see, Section CD is the main section contributing to the ammonia nitrogen pollution of the river, then followed by Section BC and Section AB.

Table 7 Division of river pollution responsibility of TP indicator

| Section     | Section AB | Section BC | Section CD |
|-------------|------------|------------|------------|
| A-A'        | 0.45       | 0.42       | 1.33       |
| B-B'        | 0.34       | 0.31       | 1.00       |
| C-C'        | 0.04       | 0.51       | 0.16       |

From the above table, the pollution responsibility index calculated by using the original detection data shows that when TP, one of the water quality indicators, travels through Section BC and Section CD, the pollution responsibility index is greater than 0, while on the contrary, the index is less than 0 when TP travels through Section AB, which indicates that this river section does not cause the pollution in the lower reaches. However, the pollution responsibility index of Section BC calculated by using the corrected TP concentration value is 0.04, indicating that this section still made certain contribution to the pollution, that is, Section AB, Section BC, and Section CD all contributed to the pollution in the lower reaches. In addition, Section 12 of the tributary also has a certain impact on the pollution of the entire river. As we can see, Section CD is the main section contributing to the TP pollution of the river, then followed by Section BC and Section AB.

Table 8 Division of river pollution responsibility for the comprehensive indicator

| Section     | Section AB | Section BC | Section CD |
|-------------|------------|------------|------------|
| A-A'        | 3.40       | 3.64       | 9.59       |
| B-B'        | 0.24       | 5.95       | -1.66      |
| C-C'        | 2.54       | 2.72       | 7.21       |
| D-D'        | 1.10       | 6.87       | 0.72       |
| Tributary   | 0.18       | 0.35       | /          |

From the above table, the pollution responsibility index calculated by using the original detection data shows that when TP, one of the water quality indicators, travels through Section BC and Section CD, the pollution responsibility index is greater than 0, while on the contrary, the index is less than 0 when TP travels through Section AB, which indicates that this river section does not cause the pollution in the lower reaches. However, the pollution responsibility index of Section BC calculated by using the corrected TP concentration value is 0.04, indicating that this section still made certain contribution to the pollution, that is, Section AB, Section BC, and Section CD all contributed to the pollution in the lower reaches. In addition, Section 12 of the tributary also has a certain impact on the pollution of the entire river. As we can see, Section CD is the main section contributing to the TP pollution of the river, then followed by Section BC and Section AB.
From the comprehensive responsibility division table of the river basin, the pollution responsibility index calculated by using the original detection data shows that the comprehensive pollution responsibility index of the river is greater than 0 in Section AB and Section BC, while the index is less than 0 in Section CD, which indicates that this river section does not cause the pollution of the lower reaches. However, the index of the river section calculated by using the corrected comprehensive value is 0.72, indicating that the section still made certain contribution to the pollution, that is, Section AB, Section BC, and Section CD all contributed to the pollution. In addition, Section 12 of the tributary also has a certain impact on the pollution of the entire river. As we can see, Section BC is main section contributing to the comprehensive pollution, then followed by Section CD and Section AB.

4. Conclusion

In this paper, the one-dimensional constant water flow quality model is used to correct the ecological compensation algorithm currently used in many provinces and cities in China. The error caused by the reduction of various pollution indicators is eliminated, and the deviation of responsibility division is avoided. The single factor analysis method and comprehensive factor analysis method are used to analyze the water quality changes of river basins under the jurisdiction of river governors at all levels and determine the water quality changes when rivers flow through the boundaries of other provinces, which provides the guidance on water dispatch for the governors.

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