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Study of the Seasonal Water Environmental Capacity of the Central Shaanxi Reach of the Wei River

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Abstract

Due to local economic development, the Central Shaanxi reach of the Wei River suffers from serious water contamination, which is restricting sustainable development in this area. Therefore, it is desirous to study the water environmental capacity here in order to improve water quality. In this paper we chose chemical oxygen demand (COD) as the index, which reflects the organic contamination. After the unit division and parameter design, we used one-dimensional steady-state model to calculate the water environmental capacity of the Central Shaanxi reach of the Wei River. The results show that the water environmental capacity of the Central Shaanxi reach of the Wei River varies with different conditions, for instance, with the months, as well as with the seasons. We have determined that seasonal pollutant load distribution and total quantity control could help us utilize the water resource more effectively.

Keywords: water environmental capacity; seasonal ; COD ; Central Shaanxi reach of the Wei River

1. Introduction

Central Shaanxi is the center of Shaanxi Province for politics, culture, and agriculture. With the implementation of the local development strategy, economic growth is rapid here. During the economic development process, however, high-polluting industries like juice-processing and paper-making which occupy great proportion of the local economy have brought an enormous amount of organic pollutants to the area. Meanwhile, environmental protection facilities and correlative environmental systems are

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immature in this area. As a result, the Central Shaanxi reach of the Wei River suffers from serious water contamination. In order to achieve social and economic sustainable development, and to provide life comforts in this area, we need to implement pollution control measures to improve water quality.

China implements total quantity control policy to prevent rivers from contamination and achieve pollution control on the basis of water environmental capacity. Water environmental capacity theory is the primary basis for water environment management, the main constraint condition of environmental planning, and the most important technical support for the total quantity control of pollutants.

Chinese scholars have studied water environmental capacity since 1970s. Since then, great progress in water quality models and water environmental capacity theories has taken place, and the water environmental capacity has been applied in city comprehensive management, water pollution control, and total quantity control [1]. When considering the theory and its practical applications, however, water environmental capacity theory lacks breakthroughs on many fronts. For instance, studies to date on water environmental capacity have been limited to the calculation of routine annual water environmental capacity under the most unfavorable conditions, without taking into consideration seasonal variations of flow volume and velocity. As a result, we cannot use water resource effectively when implementing total quantity control. In fact, weather in most Chinese districts varies remarkably with the seasons, and weather variations lead to the fact that hydrological conditions like surface runoff change seasonally, resulting in a seasonal aspect to a river's water environmental capacity. As to utilize the water resource more effectively, we need to take essential steps keeping in mind the seasonal features of a river's water environmental capacity, to direct the distribution of pollutant loads and achieve total quantity control.

As an effective measure of water environment management in a drainage area, the TMDL（Total Maximum Daily Loads）plan is carried out to restrict pollutant emissions, taking one day as the reference unit. TMDL has been proven to be effective in the ecological risk evaluation of drainage areas and in the simulation of pollutant load distribution. But due to deficiencies in technology, economics, and management experience, the majority of domestic districts cannot take one day as the reference unit for contamination control. Focusing on the Central Shaanxi segment of the Wei River, we can use the idea of TMDL as a reference point from which to study the seasonal water environmental capacity, to direct in turn the distribution of pollutant loads of COD, then to achieve total quantity control. This would make great practical significance in terms of improving the water quality of the Wei River, as well as promoting the sustainable development of Central Shaanxi.

2. Water environmental capacity model

Though scholars have had different ideas for water environmental capacity since the 1970s when water environmental capacity began to be studied in China, they all agree that water environmental capacity has the following features: water body, water quality target, and pollutant. In this paper, water environmental capacity refers to the maximum amount of specific pollutants allowed to be discharged into rivers per unit of time, based on a premise of enabling the body of water to meet water quality targets. The water environmental capacity of the Central Shaanxi segment of the Wei River is therefore the maximum amount of specific pollutants allowed to be discharged into the river every year, given the premise of meeting the water quality target set for the Wei River region's water function [2].

The water environmental capacity model is the basis for studying water environmental capacity, and model selection is the precondition for calculating water environmental capacity. Dong [3] points out that in rivers with small width-depth ratio, pollutants can be fully mixed in a very short segment and that the variety of the pollutant concentrations in each area won't be obvious. In this situation, the pollutants transferring along the river can be simulated by one-dimensional steady-state model. <Guideline for Calculation of Waste Environment Capacity, SL348-2006> shows that when a pollutant is mixed in the cross-segment, water environmental capacity can be calculated using one-dimensional model, and this model is applicable to the small and medium rivers whose flow volume is less than $150m^3/s$. Focusing on the Central Shaanxi segment of the Wei River, we propose the following hypothesises:

(1) Pollutant discharge and hydrological conditions in each period remain steady;

(2) Pollutants are fully mixed in, in cross and vertical sections, though we take only longitudinal variation into consideration.

Based on these hypothesises, we could use one-dimensional steady-state model to study the water environmental capacity of the Central Shaanxi segment of the Wei River.

Focusing on the COD contamination conditions of the Central Shaanxi segment of the Wei River, one-dimensional steady-state model can be described as:

$$U \cdot \partial C/\partial x=-KC \qquad (1)$$

Where: U, is the average velocity in the river, m/s; C, is the average COD concentration in the section, mg/L; x, is the distance between the target section and initial section, m; K, is the comprehensive degradation coefficient of COD, s^{-1}.

The solution for formula *(1)* is:

$$C_x=C_0 \cdot exp(-Kx/U) \qquad (2)$$

Where: C_x, is the pollutant concentration at the target section, mg/L. C_0, is the pollutant concentration at the initial section, mg/L.

When calculating water environmental capacity, it is relatively common to use the measures of segment-head control and segment-end control. Usually, we use the measures of segment-head control to study on rivers that have strict targets for water quality and use the measures of segment-end control to study on rivers with loose water quality targets [1]. When a body of water in a specific district suffers from serious contamination, considering accessibility, we should take steps for segment-end control. And steps for segment-head control can be taken after achieving the target by using measures of segment-end control to improve water quality step-by-step. Because of the serious contamination of the Central Shaanxi segment of the Wei River, we should be taking steps soon for segment-end control.

When using measures of segment-end control, the water environmental capacity of the segment can be described as:

$$W=(C_0-C_S) \cdot Q \qquad (3)$$

Where: W, is water environmental capacity, g/s. Q, is the flow volume of the segment, m^3/s. C_s, is the target concentration (in real rivers, considering the continuity, C_s refers to the target concentration of the upper segment), mg/L.

3. Determination of calculation conditions

3.1. Generalization of segments

The Central Shaanxi segment of the Wei River has so many branches that each branch can have an influence on the hydrological parameters. To simplify the calculation for water environmental capacity, we need to generalize the segments. The areas we studied include only the trunk stream and the main branches (the Qian River, the Shitou River, the Qishui River, the Hei River, the Lao River, the Feng River, the Ba River, the Jing River, the Shichuan River, and the Luo River).

3.2. Unit division of segment

The unit division of a segment is the precondition for calculating water environmental capacity. In this paper, we divide the segments based on the hydrological conditions and water function regionalization of the Wei River. The trunk stream and main branches of the Wei River can be divided into 57 units, including 21 units of the trunk stream and 36 units of the branches.

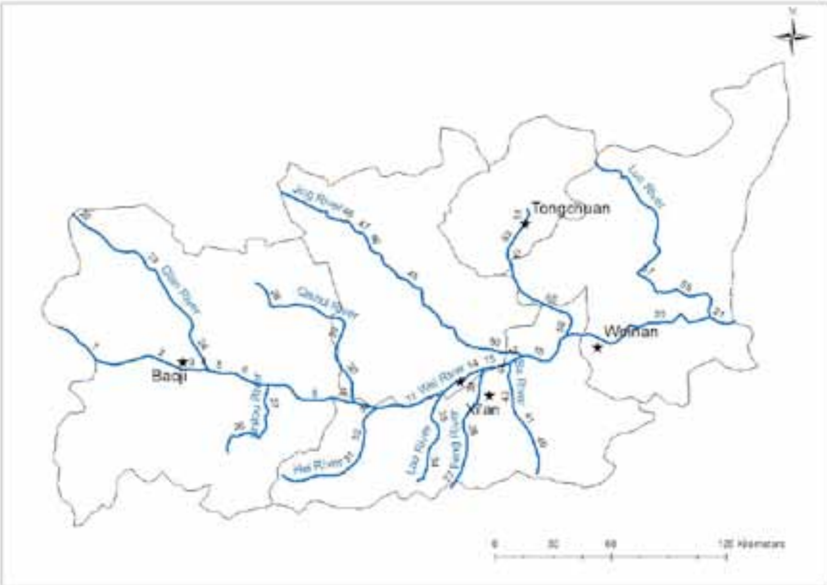

Figure 1. Annual water environmental capacity distribution of Central Shaanxi segment of Wei River (Unit: t/a)

3.3. Design of hydrological parameters

Flow volume and flow velocity are the basic hydrological parameters that influence the water environmental capacity of a river; and so they can directly influence the calculation results for water environmental capacity.

In this paper, the design flow volumes of different periods are confirmed according to the hydrological data from the hydrological stations of the trunk stream and the main branches of the Wei River. Design flow volume for the year is the average velocity of the driest month under 90% guarantee rate; design flow volume for the quarter is the average velocity of the driest month of a quarter under 90% guarantee rate; design flow volume for a month is the average velocity of the month under 90% guarantee rate.

The design velocity of each unit can be acquired from flow volume-flow velocity equation:

$$U=a \cdot Q^b \qquad (4)$$

Where: a,b, are hydraulic parameters, the values are taken from relevant studies[4].

3.4. Determination of comprehensive degradation coefficient

To determine the comprehensive degradation coefficient is an important aspect of water environmental capacity calculation. In general situations, the coefficient can be acquired by field monitoring, experimental research, and literature reference. In this paper, we use the method of literature reference. Zhang[5] points out that the comprehensive degradation coefficient is related to river type, flow conditions, landform type, and water quality target. Considering the features of each unit of the Central Shaanxi segment, we arrive at a comprehensive degradation coefficient of 0.18~0.25 d^{-1}.

4. Water environmental capacity analysis

According to the design hydrological parameters, comprehensive degradation coefficient, and the water quality target of each segment, we calculate the water environmental capacity of each unit using one-dimensional steady-state model under the scenario of segment-end control. The results follow (Figure 2,3,4,5 & Table 1). In headstreams, because of the strict water quality requirement, artificial pollutants should not be added, so we consider that there is no water environmental capacity in this case. When the water quality requirement of one segment is stricter than that for segment, it might lead to a negative water environmental capacity calculation, and so we consider in this case that there is no water environmental capacity.

The calculation results for the water environmental capacity of the Central Shaanxi segment of the Wei River show:

(1) The water environmental capacity of the Central Shaanxi segment of the Wei River is mainly distributed in the middle and lower reaches of the trunk stream, the Jing River, and the Luo River.

(2) The water environmental capacity of each segment has a significant relationship to its length, water quality target, and flow volume. Generally, the segments that are longer and have lower water quality targets and larger flow volumes have larger water environmental capacity. The longer the segment, the more thoroughly the pollutant will be degraded and the lower will be the degraded concentration. A lower water quality target for a segment will raise the upper limit of the allowed pollutant concentration. And larger flow volume will degrade more pollutant.

(3) The seasonal features of the water environmental capacity of the Wei River are obvious. The water environmental capacity is mainly concentrated in the pluvial period. The water environmental capacity of the second and third quarters are relatively larger, the first and fourth quarters lower. As to months of the year, rainfall in July and August is richer and so flow volume is larger, consequently the water environmental capacity is highest then for the year. On the other hand, rainfall in December and January is lacking, so the flow volume is lower, and so the water environmental capacity is the lowest at this time of year.

(4) Considering the seasonal aspect of the water environmental capacity of the Central Shaanxi segment of the Wei River, considered along with the usual annual water environmental capacity, the water environmental capacity achieved by looking at each month and each quarter as units of time can be larger. In sum, water environmental capacity-month > water environmental capacity-quarter > water environmental capacity-year.

Table 1 Water environmental capacity of Central Shaanxi segment of Wei River unit：$\times 10^4$t

	water environmental capacity - Year	water environmental capacity - Quarter	water environmental capacity - Month
Trunk stream	2.82	5.24	6.41
Trunk stream & branches	7.04	12.25	14.44

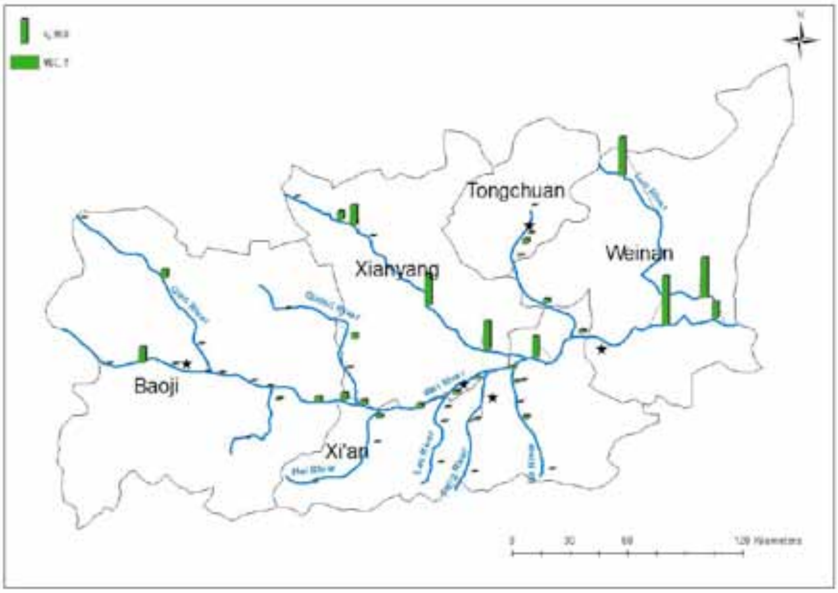

Figure 2. Annual water environmental capacity distribution of Central Shaanxi segment of Wei River (Unit: t/a)

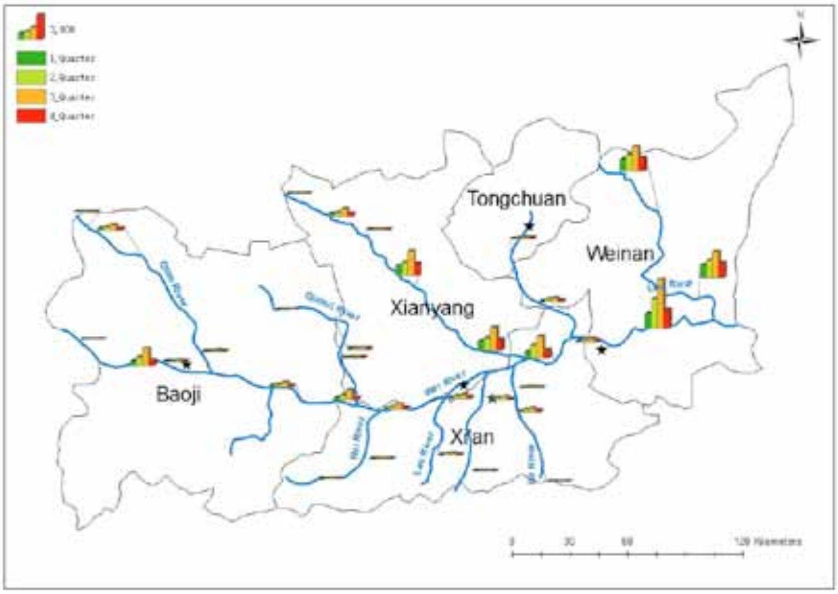

Figure 3. Quaternary water environmental capacity distribution of Central Shaanxi segment of Wei River (Unit: t/qtr)

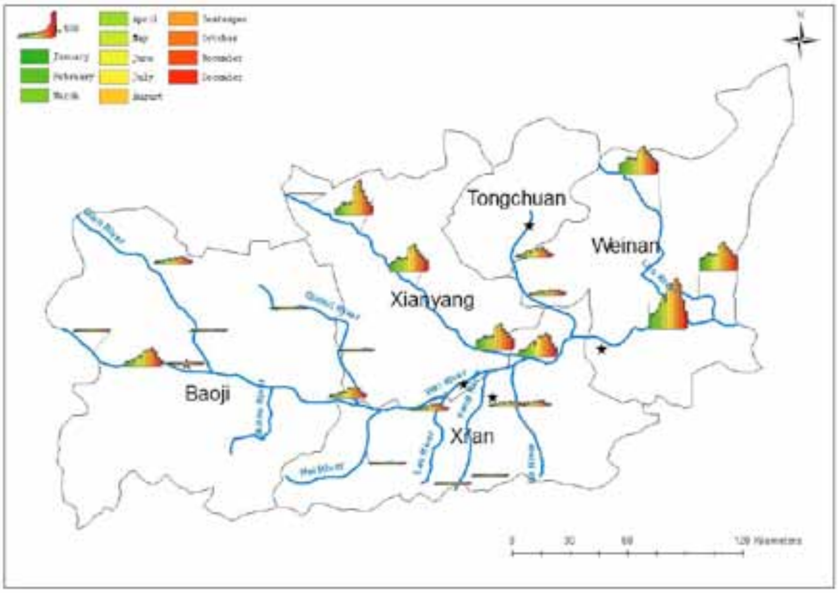

Figure 4. Monthly water environmental capacity distribution of Central Shaanxi segment of Wei River (Unit: t/ month)

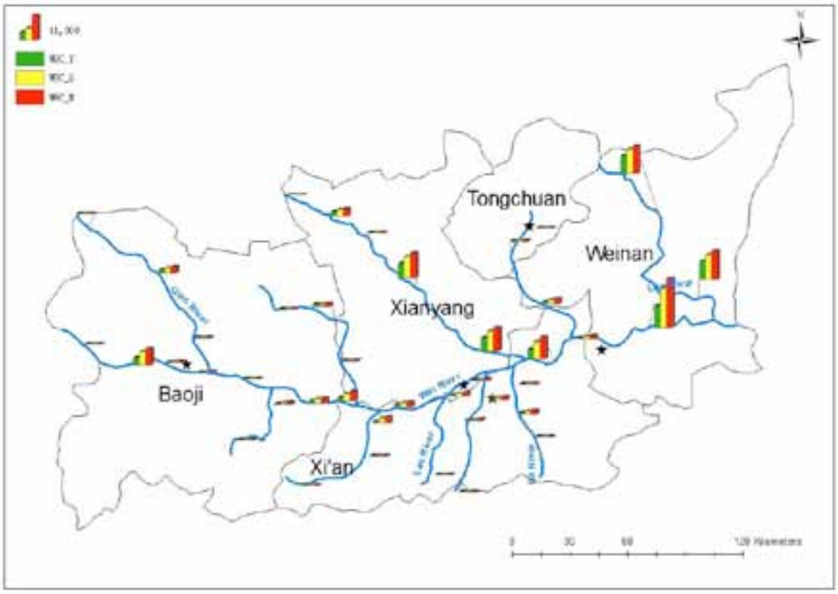

Figure 5. Annual- quaternary -monthly water environmental capacity of Central Shaanxi segment of Wei River (Unit: t/a)

5. Conclusions and suggestions

In this paper, we use one-dimensional steady-state model to study the water environmental capacity of the Central Shaanxi segment of the Wei River using the measure of segment-end control, to direct the pollutant load distribution, and total amount control to improve the ultimate water quality of the Wei River. By analyzing the results, we arrive at the following conclusions and make the following suggestions:

(1) The water environmental capacity of the Central Shaanxi segment of the Wei River is mainly distributed in the middle and lower reaches of the trunk stream, the Jing River, and the Luo River. In its economic development plan, Shaanxi Province should therefore adjust industrial distribution according to the local conditions. More industries should be allowed in the middle and lower reaches where water environmental capacity is relatively rich, and little or no industry should be allowed in the districts that have lower water environmental capacity.

(2) The length of the segment, water quality targets, and flow volumes have great influence on water environmental capacity. We could regulate the flow volume by building reservoirs and transferring water across districts, so that the water resource could be used more effectively and make for water ecological balance.

(3) The seasonal aspect of the water environmental capacity of the Wei River is obvious. The water environmental capacity in July and August is higher than that in December and January, when it is lower. By adjusting when pollutants are discharged into the river(s), including cutting down production in dry seasons or using intermittent storage to adapt to the seasonal features of water environmental capacity so as to achieve seasonal pollutant load distribution -- less pollutant load in dry season and more pollutant load in wet season -- ultimately the water resource and environmental benefit to the Wei River area could be maximized.

Acknowledgements

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