Study of sustainable development in Yongkang city based on environmental capacity and pollutant control

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Abstract. Over the past centuries, due to the improvement of the understanding of the natural environment and social service function of rivers, many countries have started the research and practice of water environment protection. China also paid most of its attentions to the water environment in most of its cities and towns. Systematic calculation and analysis of the water environment status becomes famous in most of Chinese regions, which not only shows the current status of water environment protection in China but also indicates the methods to reduce the domestic pollution. In this study, Yongkang city is selected as a typical Chinese city, COD (Chemical Oxygen Demand) and NH₃-N (Ammonia Nitrogen) are considered as two typical pollutants, both water environmental capacity and current pollution are calculated. The environmental bearing capacity coefficient is utilized to show the current status of pollution level. The comparison and analysis between the water environmental capacity and current pollution shows a good water quality status in Yongkang city. This study is also able to further improve the water quality and social development in Yongkang city in the future.

1. Introduction
Nowadays, water resources per capita in China are characterized as low level around the world[1-4], which is widely accepted due to China’s huge population. Moreover, uneven spatial and temporal distribution of water resources in China also lead to serious sustainable development problems in some offshore Chinese cities such as Yongkang in Zhejiang province[5-7]. Due to the rapid development of social economy and population, the contradiction between water resource restriction and social development is becoming much more severe than before. In this study, the analysis of Yongkang city's economy, population and water resources are made in order to figure out the water environmental capacity of this city. Additionally, the current pollution caused by economic and social development are also obtained and compared with the environmental capacity, which is calculated by collecting the relevant data such as social and economic development indicators, water resources survey and evaluation, water conservancy census, water resources planning, water resources bulletin, and other data[8-9]. The environmental bearing capacity coefficient is then introduced to represent the ratio of the current pollution and environmental capacity. Finally, the strategy of the sustainable development of Yongkang city is also made in this study to promote the balance of population, economy, water resources and environmental capacity in this typical city.
2. Evaluation of environmental capacity

In this study, the environmental capacity of water function areas in Yongkang city is calculated. The water function areas in Yongkang include two different types: mountainous river and plane river network (or reservoir). According to the characteristics of different water function areas, one-dimensional river water quality model and river network (or reservoir) water quality model are utilized.

2.1. Environmental capacity model of mountainous river

When considering mountainous river, if the flow rate is less than 150 m$^3$/s, a one-dimensional water quality model of rivers is used. The basic equation is given as [6,8]:

$$C_x = C_0 \exp \left( -\frac{Kx}{u} \right)$$

(1)

where $C_0$ (mg/L) is the pollutant concentration of the initial section; $C_x$ (mg/L) is the pollutant concentration at the $x$-distance; $x$ (m) is the longitudinal distance along the river section; $u$ (m/s) is the average velocity of the river section under the design flow. Based on the above equation, the annual environmental capacity of a certain water function area can be given as:

$$M = 31.536 \cdot b \cdot (C_x - C_0 \cdot \exp(-K \cdot L / u)) \cdot (Q \cdot K \cdot L / u) / (1 - \exp(-K \cdot L / u))$$

(2)

where $M$ (t/a) is the pollutant carrying capacity; $b$ is the coefficient of non-uniformity; $C_0$(mg/L) is the pollutant concentration of the water from the upstream section, $C_x$(mg/L) is the pollutant concentration of the downstream section, $L$(m) is the longitudinal distance between the upstream section and the downstream section; $Q$(m$^3$/s) is the design flow rate.

2.2. Environmental capacity model of river network or reservoir

When considering plain river network and reservoir, a uniform mixing model is adopted for calculating the environmental capacity, which is given as [6,8]:

$$C_t = \frac{m + m_0}{K_h \cdot V} + \left( C_s - \frac{m + m_0}{K_h \cdot V} \right) \exp(-K_h \cdot t)$$

$$K_h = \frac{Q}{V} + K$$

$$m_0 = C_0 Q L$$

(3)

(4)

(5)

where $C_t$(mg/L) is the pollutant concentration within the calculation period; $m$(g/s) is the pollutant inflow rate, $m_0$(g/s) is the pollutant discharge rate, $K_h$ is the intermediate variable; $V$(m$^3$) is the volume under the design hydrological conditions, $c_0$(mg/L) is the current pollutant concentration of the
reservoir, \( t \) is the calculation time(s), \( Q_L (\text{m}^3/\text{s}) \) is the outflow, \( C_0 (\text{mg/L}) \) is the pollution of the incoming water Substance concentration. Other symbols are the same as the previous equations.

It can be assumed that the concentration of the inflow pollutant is stable when it is fully mixed, then the pollutant carrying capacity of the plain river network (or reservoir) can be calculated according to the following equation:

\[
M = \bar{C} \cdot K \cdot V \cdot b
\]

Where \( \bar{C} (\text{mg} / \text{L}) \) is the target concentration of a certain pollutant in the river. Other symbols are the same as the previous equations.

2.3. Basic parameters

(1) Designed flow rate and velocity

All the water function areas in Yongkang city are located in the water collection area of Liantangkou station in Zhejiang province. Hence, the flow rate of each calculation area depends on the upstream precipitation of Liantangkou station, which is obtained on the basis of surface conditions, river morphology, catchment area and other factors. Additionally, according to the research results of National Water Resources Protection Plan (Zhejiang part) (2010-2030) [9], the representative flow stations with long series data in Zhejiang province are also analysed and compared with the designed flow rate to improve its accuracy.

(2) Comprehensive degradation coefficient

The comprehensive degradation coefficient \( K \) of different pollutants includes the COD (Chemical Oxygen Demand) and \( \text{NH}_3\text{-N} \) (Ammonia Nitrogen) in this study are obtained fully based on previous research. According to the National Water Resources Protection Plan (Zhejiang part) and other relevant reports, the degradation coefficient of corresponding pollutants is selected for each water function area in Yongkang city. Eventually, the comprehensive degradation coefficient \( K \) for COD are 0.25 and 0.035 for mountainous river and plain river network (or reservoir), respectively, while for \( \text{NH}_3\text{-N} \) are 0.15 and 0.024 for mountainous river and plain river network (or reservoir), respectively.

2.4. Environmental capacity of water function areas

In this study, the environmental capacity of each water functional area is calculated based on the hydrological guaranteed rates of 90%, 75% and 50%, respectively. Table 1 shows the environmental capacity calculation results of all the water function areas in Yongkang city. It is clear that higher hydrological guaranteed rate leads to a lower environmental capacity, vice versa.

![Figure 2. Water function areas in Yongkang city (Blue for water quality target II and Green for III)](image-url)
| Water function area | River system       | Water quality target | COD (%) | NH₃-N (%) |
|---------------------|--------------------|----------------------|---------|-----------|
|                     |                    | 90%  | 75%  | 50%  | 90% | 75% | 50% |
| 1                   | Qiantangjiang river system | II   | 890.22 | 1065.04 | 1233.66 | 17.54 | 19.90 | 20.42 |
| 2                   | Qiantangjiang river system | III  | 2059.98 | 2494.23 | 3013.19 | 62.36 | 77.23 | 97.08 |
| 3                   | Qiantangjiang river system | II   | 1006.69 | 1203.86 | 1427.16 | 19.97 | 23.92 | 28.38 |
| 4                   | Qiantangjiang river system | II   | 528.53  | 637.30  | 760.48  | 10.57 | 12.75 | 15.21 |
| 5                   | Qiantangjiang river system | II   | 1028.54 | 1208.58 | 1412.47 | 20.06 | 23.66 | 27.74 |
| 6                   | Qiantangjiang river system | II   | 1897.37 | 2287.85 | 2730.48 | 46.88 | 56.55 | 67.81 |
| 7                   | Qiantangjiang river system | II   | 104.23  | 125.13  | 148.81  | 2.08  | 2.49  | 2.97  |
| 8                   | Qiantangjiang river system | II   | 82.10   | 98.45   | 116.97  | 1.63  | 1.96  | 2.33  |
| 9                   | Qiantangjiang river system | III  | 1462.97 | 1764.04 | 2105.04 | 43.89 | 52.92 | 63.24 |
| 10                  | Qiantangjiang river system | II   | 293.00  | 349.24  | 412.94  | 5.79  | 6.92  | 8.19  |
| 11                  | Oujiang river system  | II    | 8.15    | 11.99   | 18.38   | 0.31  | 0.49  | 0.81  |

3. Evaluation of current pollution in different water function areas

According to the field investigation, all the industrial pollution in Yongkang city has been transferred to four different sewer plants. Hence, Yongkang city's current pollution can be mainly divided into four categories, including urban living pollution, rural living pollution, livestock and poultry pollution, and agricultural non-point sources pollution. The above four categories of pollution sources are analyzed and calculated respectively. Moreover, the pollutant discharges from the sewer plant is considered in the category of urban living pollution.

3.1. Evaluation of current pollution

According to the Statistical Yearbook of Yongkang city [10], citizen census and other data of this typical city, the population in urban and rural areas of Yongkang city is 255,000 and 360,000. In total four sewer plants located in different districts in Yongkang city with the sewer discharge of 120,000t/d, 20000t/d, 5000t/d and 4000t/d.

In this study, serious kinds of basic data and relevant regulations of Yongkang city are collected to calculate the current pollution, while the total pollution is then decomposed to the corresponding water function area based on the spatial distribution of pollution sources.

Table 2 and Table 3 show the calculation results of COD and NH₃-N pollution load of each pollution source in different water function area.

Table 2. Calculation of COD in different water function area

| Water function area | Types       | Urban living pollution | Rural living pollution | Livestock and poultry pollution | Agricultural non-point sources | In total |
|---------------------|-------------|------------------------|------------------------|--------------------------------|-------------------------------|---------|
| 1                   | River       | 0.0                    | 27.2                   | 0.6                            | 7.2                           | 35.0    |
| 2                   | River       | 2108.2                 | 172.3                  | 1.0                            | 18.8                          | 2300.3  |
| 3                   | Reservoir   | 0.0                    | 15.9                   | 0.0                            | 5.0                           | 20.9    |
Table 3. Calculation of NH3-N in different water function area

| Water function area | Types | Urban living pollution | Rural living pollution | Livestock and poultry pollution | Agricultural non-point sources | In total |
|---------------------|-------|------------------------|------------------------|-------------------------------|-------------------------------|---------|
|                     |       | (t/a)                  | (t/a)                  | (t/a)                         | (t/a)                         | (t/a)   |
| 1                   | River | 0                      | 1.6                    | 0.1                           | 0.6                           | 2.3     |
| 2                   | River | 70.3                   | 20.7                   | 0.1                           | 1.6                           | 92.7    |
| 3                   | Reservoir | 0                  | 0.7                    | 0.0                           | 0.4                           | 1.1     |
| 4                   | River | 0.9                    | 0.7                    | 0.3                           | 0.3                           | 2.2     |
| 5                   | Reservoir | 0                | 1.0                    | 0.0                           | 0.3                           | 1.3     |
| 6                   | River | 13.8                   | 27.5                   | 0.2                           | 2.1                           | 43.6    |
| 7                   | Reservoir | 0                 | 0.0                    | 0.0                           | 0.0                           | 0.0     |
| 8                   | Reservoir | 0                | 0.5                    | 0.0                           | 0.4                           | 0.9     |
| 9                   | River | 1.6                    | 13.6                   | 0.2                           | 0.6                           | 16      |
| 10                  | Reservoir | 0                | 0.4                    | 0.0                           | 0.0                           | 0.4     |
| 11                  | Reservoir | 0                 | 0.2                    | 0.0                           | 0.0                           | 0.2     |
| Summary             |       |                        |                        |                               |                               | 86.6    |
|                     |       |                        |                        |                               |                               | 66.9    |
|                     |       |                        |                        |                               |                               | 1.0     |
|                     |       |                        |                        |                               |                               | 6.5     |
|                     |       |                        |                        |                               |                               | 160.7   |

3.2. Comparison and analysis

As shown in Table 1 to Table 3, there are 11 water function areas in Yongkang city. According to the analysis and calculation of the current pollution, the amount of COD and NH3-N in Yongkang city are 3346.1t/a and 160.7t/a, respectively. While the amount of theoretical environmental capacity in all the water function areas of COD and NH3-N are 4370.8t/a and 160.9t/a, respectively. Therefore, the environmental bearing capacity coefficient of COD and NH3-N, which is the ratio of current pollution and environmental capacity, are 0.8 and 1.0 respectively. As a result, the current pollution in Yongkang city is not overloaded when considering 90% hydrological guaranteed rate. The detailed environmental bearing capacity coefficient in all the 11 water function areas is shown in Table 4.

Table 4. Comparison and analysis of COD and NH3-N in different water function area

| Water function area | COD (t/a) | NH3-N (t/a) | P/P0 Higher value | Final status |
|---------------------|-----------|-------------|-------------------|--------------|
|                     | P         | P0(90%)     | Status            |              |
|                     | P         | P/P0        | Status            |              |
|                     | P         | P/P0        | Status            |              |
| 1                   | 35        | 35          | 1 Good            |              |
|                     | 230.3     | 2060        | 1 Overload        |              |
| 3                   | 209       | 209         | 1 Good            |              |
| 4                   | 35.4      | 35.4        | 1 Good            |              |
| 5                   | 17.5      | 17.5        | 1 Good            |              |
As shown in Table 4, 10 of 11 water function areas are in good status with the environmental bearing capacity coefficient less than 1, which means that most of the water function areas in Yongkang city are in good status, and the current pollutant discharges in those water function areas are less than the environmental capacity. However, there is still one water function area in Yongkang city behaves in overload status, in which the COD and NH$_3$-N environmental bearing capacity coefficients are 1.1 and 1.5, respectively. The reason of this overloaded area appears is that the sewer plant with 150,000t/d located in this water function area, the sewer discharge actually contributes almost 80% of the current pollution in this water function area and eventually leads to a huge amount of COD and NH$_3$-N pollution, therefore, the environmental bearing capacity coefficient of both COD and NH$_3$-N are both greater than 1.0 in this water function area.

4. Conclusion
Due to the scientific and reasonable management of water environment, Yongkang city has achieved good status in water quality and water resource protection. The overall water quantity and quality in Yongkang city are not overloaded, and the water environment continues to improve. In this study, COD and NH$_3$-N are represented as the control indicators, in total 11 water function areas in Yongkang city are selected as research zones. The calculation and comparison between current pollution and water environmental capacity shows that the water quality in most of the water function areas are in good condition, only one water function area are in overloaded status due to a huge sewer plant has been constructed in this special water function area. The comparison and analysis in this study will be a good tool to improve the water quality and social development in Yongkang city in the future.

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