Calculation of environmental capacity and pollutant discharge in Changxing county based on sustainable development

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Abstract. Due to the improvement of the understanding of the natural environment and social service function of rivers, many countries in the world have started the research and practice of water environment protection. Lots of Chinese cities also paid most of their attentions to the water environment especially in the river network area. Systematic calculation and analysis of the water environment status becomes famous in most of the Chinese cities, which not only shows the current status of water environment but also indicates the methods to reduce the domestic pollution. In this study, Changxing county is selected as a typical Chinese city, COD (Chemical Oxygen Demand) and TN (Total Nitrogen) are considered as two typical pollutants, both water environmental capacity and current pollution are calculated. From the comparison between the present pollution load and the discharge limit into the river, it can be seen that TN is the key influencing factor of the water environment carrying capacity in Changxing County, and its overload ratio is up to 5.0. A series of measures to reduce the pollution load into the river are put forward in order to provide an auxiliary decision-making basis for further protecting “clear water and green mountains”.

1. Introduction
The quality of water environment relates to the safety of drinking water and the human settlement environment in the region [1]. With the continuous development of social productive forces, the rapid expansion of urban population has led to the discharge of a large number of production and life into the river, making the river seriously polluted [2]. Water environmental capacity is defined as the amount of pollution load that can be carried by the water environment under certain hydrological conditions and water quality objectives, on the premise of ensuring water environmental functions and uses [3]. As an important quantitative index of water quality, water environmental capacity is an important basis to guide the reduction of pollution load by water pollution control engineering measures [4]. Chen Hanwen et AL proposed to reduce the pollution load into the lake based on the environmental capacity [5].

2. Research object
Located in the hangzhou-jiaxing-huzhou area of northern Zhejiang Province, Changxing County is known as the “pearl of Tai Lake” for its outstanding landscape features and Superior Natural Environment. Changxing county is one of the country’s top 100 counties, with the province ranked first in terms of economic strength (see Figure 1). A few years ago, Changxing county’s water quality was not up to standard because it was not important enough to protect the environment. In recent years, with the advance of five waters co-management, the water environment in Changxing County has improved obviously, but there is still some substandard water quality in some areas, and blue-green
algae still occur every year in the Tai Lake River downstream. In this study, the analysis of Changxing county’s economy, population, water resources are made in order to figure out the water environmental capacity of this city. According to the research results of National Water Resources Protection Plan (Zhejiang part) (2010-2030) [6], the Statistical Yearbook of Changxing [7], collect the data of social and Economic Development Index, water resources survey and evaluation, Water Resources Survey, water resources planning, Water Resources Bulletin and so on, the current environmental pollution quantity was calculated, and the carrying capacity Coefficient of Changxing County was put forward for the first time. Finally, the strategy of the sustainable development of Changxing county are also made in this study to promote the balance of population, economy, water resources and environmental capacity in this typical city.

Figure 1. Location and river system in Changxing county.

3. Method for calculating environmental capacity
In this study, the environmental capacity of water function areas in Changxing county is calculated. The water function areas in Changxing include three different types: mountainous river plane, river network and 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.

3.1. Environmental capacity model of mountainous river
The calculation models and methods of the carrying capacity of water area are specified in the regulation of carrying capacity of water area(SL348-2006) [8]. When considering mountainous river, if the flow rate of river is less than 150m$^3$/s, a one-dimensional water quality model of rivers is used. The basic equation is given as [9]:

$$C_i = C_0 \exp \left( -\frac{Kx}{u} \right)$$  \hspace{1cm} (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, $K$ (s$^{-1}$) is the comprehensive attenuation coefficient of pollutant.

3.2. 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]:

$$C_t = \frac{m + m_0}{K_iV} + \left( C_s - \frac{m + m_0}{K_iV} \right) \exp (-K_i t)$$  \hspace{1cm} (2)

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, $K_i$ is the intermediate variable; $V$ (m$^3$) is the volume
under the design hydrological conditions, $C_i (\text{mg/L})$ is the current pollutant concentration of the reservoir, $t$ is the calculation time(s), others symbols are the same as in the previous equations.

3.3. Basic parameters

(1) Designed flow rate and velocity

All the water function area in Changxing county is located in the catchment area of Changxing Station (II). The sectional discharge values of each calculation unit in each water function area can be calculated according to the designed discharge values of the station. The discharge of each calculation unit depends on many factors, such as upstream precipitation, underlying surface condition, river shape, catchment area, etc. Additionally, according to the research results of National Water Resources Protection Plan (Zhejiang part) (2010-2030) [6], taking into account the situation of the Changxing County River Basin and the distribution of discharge stations in the corresponding basin, the daily discharge and water level data of the Changxing Station (II) in the basin from 1978 to 2017 are used to calculate the monthly average discharge annually, the minimum monthly average flow rate is 0.11 m$^3$/s. The minimum monthly average flow rate is 90%.

(2) Comprehensive degradation coefficient

The comprehensive degradation coefficient $K$ of different pollutants includes the COD (Chemical Oxygen Demand) and TN (Total Nitrogen) in this study is obtained fully based on previous research. According to the National Water Resources Protection Plan (Zhejiang part) [6] and the relevant research results in Hangzhou, Huzhou, Taizhou, Ningbo and other places [10], the degradation coefficient of corresponding pollutants is selected for each water function area in Changxing county. Eventually, the comprehensive degradation coefficient $K$ for COD are 0.25 and 0.04 for mountainous river and plain river network (or reservoir), respectively, while for TN are 0.15 and 0.06 for mountainous river and plain river network (or reservoir), respectively.

![Figure 2. Water function areas in Changxing county (Blue for water quality target II and Green for III).](image-url)
4. Calculation results

4.1. Environmental capacity of water function areas

In this study, the environmental capacity of each water functional area is calculated according to the hydrological guaranteed rates of 90%(Low water year), 75%(relative low water year) and 50%(normal water year), respectively. Figure 2 shows the location of each water function area. Table 1 shows the environmental capacity calculation results of all the water function areas in Changxing county. The higher the hydrological guarantee rate, the smaller the environmental capacity.

| Water function area | River system      | Water quality target | COD 90% | 75% | 50% | TN 90% | 75% | 50% |
|---------------------|-------------------|----------------------|---------|-----|-----|--------|-----|-----|
| 1                   | Hangjiahu Plain River system | III                  | 367.57  | 443.07 | 628.52 | 11.03 | 13.29 | 3.02 |
| 2                   | Tiao river system  | III                  | 74.13   | 93.63 | 147.95 | 3.29  | 4.41  | 1.46 |
| 3                   | Tiao river system  | III                  | 20.39   | 24.58 | 34.87  | 0.41  | 0.49  | 0.11 |
| 4                   | Tiao river system  | II                   | 118.26  | 118.26 | 118.26 | 0.3   | 0.3   | 0.01 |
| 5                   | Tiao river system  | II                   | 70.27   | 84.7  | 120.15 | 1.41  | 1.69  | 0.38 |
| 6                   | Tiao river system  | II                   | 183.07  | 224.49 | 333.34 | 6.36  | 8.13  | 2.35 |
| 7                   | Tiao river system  | II                   | 367.57  | 443.07 | 628.52 | 11.03 | 13.29 | 3.02 |
| 8                   | Tiao river system  | II                   | 114.95  | 138.56 | 196.56 | 3.45  | 4.16  | 0.94 |
| 9                   | Tiao river system  | II                   | 605.75  | 605.75 | 605.75 | 1.51  | 1.51  | 0.04 |
| 10                  | Tiao river system  | II                   | 23.42   | 25.31 | 30.8   | 0.47  | 0.51  | 0.1  |
| 11                  | Tiao river system  | II                   | 87.1    | 94.61 | 117.06 | 1.97  | 2.18  | 0.52 |
| 12                  | Tiao river system  | III                  | 197.62  | 215.5 | 269.3  | 7.2   | 8     | 1.86 |
| 13                  | Tiao river system  | II                   | 19.44   | 26.94 | 42.97  | 0.39  | 0.54  | 0.14 |
| 14                  | Tiao river system  | III                  | 30.91   | 45.08 | 80.1   | 1.17  | 1.86  | 0.71 |
| 15                  | Tiao river system  | III                  | 32.04   | 44.4 | 70.82  | 0.96  | 1.33  | 0.34 |
| 16                  | Tiao river system  | III                  | 727.69  | 727.69 | 727.69 | 54.58 | 54.58 | 9.1  |
| 17                  | Tiao river system  | III                  | 684.16  | 684.16 | 684.16 | 51.31 | 51.31 | 8.55 |
| 18                  | Tiao river system  | III                  | 304.76  | 304.76 | 304.76 | 22.86 | 22.86 | 3.81 |
| 19                  | Tiao river system  | III                  | 945.38  | 945.38 | 945.38 | 70.9  | 70.9  | 11.82 |
| 20                  | Tiao river system  | III                  | 1181.72 | 1181.72 | 1181.72 | 88.63 | 88.63 | 14.77 |
| 21                  | Tiao river system  | II                   | 132.61  | 143.85 | 177.28 | 2.91  | 3.21  | 0.74 |
| 22                  | Tiao river system  | III                  | 252.27  | 393.54 | 551.84 | 6.56  | 9.52  | 2.01 |
| Summary             |                   |                      | 6173.51 | 6565.98 | 7369.28 | 337.67 | 349.41 | 62.78 |

4.2. Pollution load of water functional areas

Changxing county’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, while the pollutant discharges from the sewer plant is considered in the category of urban living pollution.

According to the Statistical Yearbook of Changxing [10], county citizen census and other data of this typical city, the population in urban and rural areas of Changxing county is 346,400 and 290,000 respectively. According to the field investigation, all the industrial pollution in Changxing county has been transferred to thirteen with the sewer discharge of total 24,300t/d. In addition, there are 76,748 pigs, 513 cattle, 79,218 sheep and 1255585 feathers of various poultry in Changxing County, and 60,922 tons of fish and other aquaculture products. Rice and fruit trees are the main agricultural crops in Changxing County, with a total area of 1.1724 million mu of arable land and garden land.
In this study, serious kinds of basic data and relevant regulations of Changxing county are collected to calculated 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 Figure 3 show the calculation results of COD and TN pollution load of each pollution source in different water function area.

| Water function area | Types     | COD(t/a) | TN(t/a) | Water function area | Types     | COD(t/a) | TN(t/a) |
|---------------------|-----------|----------|---------|---------------------|-----------|----------|---------|
| 1 River             | River     | 730      | 219     | 13 River            | River     | 118.8    | 34.8    |
| 2 River             | River     | 238.9    | 63.9    | 14 River            | River     | 433.6    | 128     |
| 3 River             | River     | 133.7    | 38      | 15 River            | River     | 596.7    | 177.9   |
| 4 Reservoir         | Reservoir | 12.8     | 3       | 16 River            | River     | 49.5     | 12.7    |
| 5 Reservoir         | Reservoir | 28.7     | 6.6     | 17 River            | River     | 72.4     | 18.9    |
| 6 River             | River     | 129.3    | 36.4    | 18 River            | River     | 21.5     | 5.4     |
| 7 River             | River     | 382.2    | 103.1   | 19 River            | River     | 899.9    | 267.2   |
| 8 River             | River     | 284.5    | 79.9    | 20 River            | River     | 66.5     | 17.7    |
| 9 Reservoir         | Reservoir | 37       | 10.4    | 21 River            | River     | 115.7    | 31      |
| 10 River            | River     | 164.4    | 48.5    | 22 River            | River     | 14.1     | 3.6     |
| 11 Reservoir        | Reservoir | 83.3     | 23.5    | Summary             |           |          |         |
| 12 River            | River     | 1178.1   | 351.5   |                     |           |          |         |

**Figure 3.** Percentage chart of COD sources in 22 water function areas.

4.3. Environmental bearing capacity and control countermeasures

As shown in Table 1 to Table 2, there are 22 water function areas in Changxing county. According to the analysis and calculation of the current pollution, the amount of COD and TN in Changxing county are 5791.6t/a and 1677.8t/a, respectively. While the amount theoretical environmental capacity in all the water function areas of COD and TN are 5487.0t/a and 1677.8t/a, respectively. Therefore, the environmental bearing capacity coefficient of COD and TN, which is the ratio of current pollution and
environmental capacity, are 1.1 and 5.1 respectively. As a result, the current pollution in Changxing county is severe overloaded when considering 90% hydrological guaranteed rate. The detailed environmental bearing capacity coefficient in all the 22 water function areas are shown in Table 3.  

Table 3. Comparison and analysis of COD and TN in different water function area.

| Water function area | COD(t/a) | TN(t/a) | P/P0(90%) | Status | P | P0(90%) | Status | Higher value | Final status |
|---------------------|----------|---------|-----------|--------|---|---------|--------|-------------|-------------|
| 1                   | 730      | --      | --        | 219    | -- | --      | --     | --           | --          |
| 2                   | 238.9    | 367.6   | 0.6       | Good   | 63.9| 11      | 5.8    | Severe      | 58          |
| 3                   | 133.7    | 74.1    | 1.8       | Overload| 38 | 3.3     | 11.5   | Severe      | 11.5        |
| 4                   | 12.8     | 12.8    | 1.0       | Good   | 3  | 0.4     | 7.5    | Severe      | 7.5         |
| 5                   | 28.7     | 28.7    | 1.0       | Good   | 6.6| 0.3     | 22.0   | Severe      | 22.0        |
| 6                   | 129.3    | 70.3    | 1.8       | Overload| 36.4| 1.4    | 26.0   | Severe      | 26.0        |
| 7                   | 382.2    | 183.1   | 2.1       | Overload| 103.1| 6.4   | 16.1   | Severe      | 16.1        |
| 8                   | 284.5    | 115.7   | 2.5       | Overload| 79.9| 3.5    | 22.8   | Severe      | 22.8        |
| 9                   | 37       | 37      | 1.0       | Good   | 10.4| 1.5    | 6.9    | Severe      | 6.9         |
| 10                  | 164.4    | 23.4    | 7.0       | Severe | 48.5| 0.5    | 97.0   | Severe      | 97.0        |
| 11                  | 83.3     | 83.3    | 1.0       | Good   | 23.5| 2      | 11.8   | Severe      | 11.8        |
| 12                  | 1178.1   | 197.6   | 6.0       | Severe | 351.5| 7.2   | 48.8   | Severe      | 48.8        |
| 13                  | 1188.8   | 19.4    | 6.1       | Severe | 34.8| 0.4    | 87.0   | Severe      | 87.0        |
| 14                  | 433.6    | 30.9    | 14.0      | Severe | 128 | 1.2    | 106.7  | Severe      | 106.7       |
| 15                  | 596.7    | 32      | 18.6      | Severe | 177.9| 1     | 177.9  | Severe      | 177.9       |
| 16                  | 49.5     | 727.7   | 0.1       | Good   | 12.7| 54.6   | 0.2    | Good        | 0.2         |
| 17                  | 72.4     | 684.2   | 0.1       | Good   | 18.9| 51.3   | 0.4    | Good        | 0.4         |
| 18                  | 21.5     | 304.8   | 0.1       | Good   | 5.4 | 22.9   | 0.2    | Good        | 0.2         |
| 19                  | 899.9    | 945.4   | 1.0       | Good   | 267.2| 70.9  | 3.8    | Severe      | 3.8         |
| 20                  | 66.5     | 1181.7  | 0.1       | Good   | 17.7| 88.6   | 0.2    | Good        | 0.2         |
| 21                  | 115.7    | 115.7   | 1.0       | Good   | 31  | 2.9    | 10.7   | Severe      | 10.7        |
| 22                  | 14.1     | 252.3   | 0.1       | Good   | 3.6 | 6.6    | 0.5    | Good        | 0.5         |
| total               | 5791.6   | 5487.0  | 1.1       | Critical state | 1677.8| 337.67| 5.0    | Severe      | 5.0         |

Note: P represents the current pollution, P0 represents the environmental capacity.

From the point of Changxing county in 2018 water quality monitoring results, COD concentration in the range of the $\text{II} \sim \text{III}$ all is better than that of water function area water quality requirements; TN concentration is all within III~V, and most of them exceed the water quality requirements of water functional areas, which is the main pollution index. As shown in Table 3, Among the 22 water function areas in the county, COD index of 5 water function areas and TN index of 16 water function areas were seriously overloaded, which was basically consistent with the water quality monitoring results.

As shown in Table 3 and Figure 4, the overall evaluation of COD and TN is critical state and serious overload state respectively. The concentration of TN is obviously higher than COD, which is the main overload factor. 16 of 22 water function zones are seriously overloaded and the remaining 5 are good from the point of view of location, most of the overload water function zones are located in Hexi Xingang and Changxing Port (only one is located in Siantang river). The reason of this overloaded area appears is that there are 13 sewage treatment in Changxing County, the present standard of effluent treatment is grade A, the limit of TN concentration in tail water is 15mg/L, which is 15 times of the limit of 1mg/L of III type surface water, and the overall scale of treatment in Changxing county is large, the dispersion of the discharge and the occasional over-discharge caused
the serious overloading of TN in the whole county to a great extent. In addition, there is widespread leakage in the sewerage networks in the old town area of Changxing County. When the river water level is low, untreated sewage flows through the underground water networks into Hexi channel and Changxing channel. On rainy days, due to incomplete diversion of rainwater and sewage, a large amount of rainwater enters the sewage treatment plant, it also increases the treatment load of the sewage plant and causes the deterioration of the tail water quality.

Reference “HuZhou city water environment comprehensive treatment plan”, “Changxing county water environment rectification work plan”, “ZheJiang province tai lake basin water environment comprehensive treatment plan” and so on, and combined with the report on the bearing capacity of the Changxing county water resources and the status quo into the river pollutants calculation results, Changxing county of pollution control measures are put forward Suggestions, Changxing county has proposed the following pollution control measures: By the end of 2025, domestic sewage in urban built-up areas will basically be fully collected and fully treated, the coverage of rural domestic sewage treatment administrative villages has reached 100%, the benefit rate of farmers has reached over 90%, the proportion of qualified villages in rural environment has reached 100%, 100% of town blocks and over 95% of administrative villages have realized waste separation treatment, the regulation rate of large-scale Livestock and poultry farms has reached over 90% and the comprehensive utilization rate of Excreta of large-scale livestock and poultry farms has reached over 99%.

5. Conclusions and recommendations

5.1. Conclusions
(1) In this study, COD and TN are represented as the control indicators, in total 22 water function areas in Changxing county are selected as research zones. In 2018, the water quality of all water functional areas had good COD and poor TN.

(2) A one-dimensional river water quality model and river network (or reservoir) water quality model was used to calculate the environmental capacity of each water functional area under the conditions of 90%(low water years), 75%(relatively low water years) and 50%(normal water years) of
the hydrological guarantee rate. Under different hydrological guarantee rates, the environmental capacity of COD and TN is 6173.51 t/a, 6565.98 t/a, 7369.28 t/a and 337.67 t/a, 349.41 t/a, 62.78 t/a respectively.

(3) According to the calculation of various types of river pollution in 2018, the amount of COD and TN in Changxing county are 5791.6t/a and 1677.8t/a, respectively.

(4) Through the calculation and comparison of the existing pollution and water environmental capacity, TN is the key influencing factor of water environmental carrying capacity in Changxing County, and its overload ratio is 5.0.

5.2. Recommendations

(1) Control of pollution for entering rivers shall be strengthened, with the emphasis on the reduction of the pollution source from urban living and rural living, including the new construction, reconstruction and expansion of the urban Sewage Treatment, and the reduction of fertilizer and pesticide application in the farmland Livestock and poultry farm pollution control, river sediment dredging, etc.

(2) According to the calculation, after the implementation of various emission reduction measures, the total nitrogen (TN) pollution into the river will be reduced by about 60%, but it is still far beyond the limit of TN discharge into the river.

Acknowledgments

This research was supported in part by the National Water Pollution Control and Treatment Science and Technology Major Project(2018ZX07208-009-03), the Science and Technology Plan Project of Department of Water Resources of Zhejiang Province (RA1905), the National Nature Science Foundation of China (51709237), the Special Support Program for Provincial Scientific Research Institutes of Zhejiang (ZH-A20003).

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