Comparison of river network health status in two typical Chinese cities considering water diversion project

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Abstract. In the last decades, water quality of river network in most Chinese cities has been worse than before due to the huge amount of wastewater discharges. Hence, in order to improve the river network environment, numbers of water diversion projects have been constructed in lots of these cities, which are widely acknowledged as effective projects to accelerate the river network flow rate and enhance the environmental capacity. In this study, two typical river networks are selected, which are Jiaxing river network and Wenzhou river network, located in northern and southern Zhejiang province, respectively. Since the water diversion projects in these two cities have been constructed and operated for years, it is necessary to evaluate the water quality improvements as well as the social benefits using a comprehensive evaluation system. Moreover, the health status comparison of these two different river networks is also made in this study to show the discrepancies between these two typical Chinese cities. The analysis and results in this study will be widely used in other Chinese cities in the future as a decision-making method for the construction of water diversion projects.

1. Introduction
The plain river network is dense and connected with each other; the flow direction and flow pattern of the river network are random in the natural state. Indeed, the river network system is complex, which is not only affected by the inflow of the river basin, but also closely related to the upstream reservoirs, tributaries and the tidal bore of the downstream offshore area [1-3]. However, due to the characteristics of the river network itself, the flow rate of the river network is relatively slow, the self-purification ability is poor, and the water pollution problem is easy to break out [4-6].

Zhejiang is a typical coastal province in China, but due to the process of urbanization, the environment phenomenon of river networks in Zhejiang province has been much worse than before [3,4]. On the one hand, the narrow river network increases the risk of flood control and drainage; on the other hand, the self-purification ability of the river network will also reduce due to the slow water flow rate.

The earliest water diversion project constructed in order to improve river water quality began in Japan, which diverted 16.6 m³/s of clean water from Rigenkawa and Arakawa in 1964 [6-9]. Moreover, in order to solve the problems of saltwater intrusion and wetland shrinkage in New Orleans, the U.S. Army Corps of Engineers and the Louisiana State have implemented a water diversion project to replenish fresh water from the Mississippi River to New Orleans, which effectively restored coastal wetlands and improved the water ecological environment. In China, the first practice of water diversion appears in Shanghai in the mid-1980s, which effectively improved the river network water quality in Shanghai city [9]. Nowadays, lots of Chinese cities, such as Hangzhou, Suzhou, and Jiaxing...
have constructed different water diversion projects to improve the city river network and show great benefits in water environment.

Recently, a huge numbers of water diversion projects are constructed and operated in lots of Chinese cities especially in the offshore area such as Zhejiang province. It is necessary to monitor and analyze the environmental effects of these water diversion projects. In this study, two typical cities in Zhejiang province are selected, which are Wenzhou city and Jiaxing city, located in south and north part of the province, respectively. Both of them are highly developed cities and have typical plain river networks in the city area, as shown in Figure 1.

![Figure 1. River network in Zhejiang province.](image)

2. Methodology

Due to the importance of both the river network and the field water diversion project, it is necessary to evaluate the health of the river network basin for realizing the sustainable development of the society. In this study, a comprehensive evaluation system has been established based on previous research in order to assess the river network health status before and after water diversion, which consists of two-level indicators [3,8-9]. It is also indicated by previous research that this evaluation method is convincing and suitable for river network health assessment, which has been utilized in the evaluation of river network in Shanghai city previously[8,9]. The method is shown in Table 1.

| Main               | 1st level indicator       | 2nd level indicator               | Weight |
|--------------------|----------------------------|-----------------------------------|--------|
| River network health status | Natural environment (0.54) | Water quality                     | 0.22   |
|                    |                            | Ratio of Water Surface (%)        | 0.22   |
|                    |                            | River numbers                     | 0.11   |
|                    |                            | Network complexity                | 0.22   |
|                    |                            | Soil pollutant level              | 0.11   |
|                    |                            | Basin dense (1/km²)               | 0.22   |
|                    | Human activities impact (0.30) | GDP per unit area (Billion/km²)   | 0.51   |
|                    |                            | Population per unit area (P/km²)  | 0.11   |
|                    |                            | Pollution per unit area (T/km²)   | 0.06   |
|                    |                            | Water consumption per unit area (T/km²) | 0.06 |
|                    |                            | Environmental budget per unit area (Million/km²) | 0.26 |
| Risk effects (0.16) |                            | Ratio of impermeable area (%)     | 0.5    |
|                    |                            | Environmental flow rate           | 0.25   |
|                    |                            | Natural risk index                | 0.25   |
As shown in Table 1, secondary indicators composed of fourteen basic indices [10-13]. Among them, six secondary indicators belong to natural environment, five secondary indicators belong to human activities impact and three secondary indicators belong to risk effects. Each secondary indicator has its own evaluation method and criteria, as shown in Table 2. The river network health status will be evaluated based on the score of the following equation[8,9].

\[ E = W_f \times I + W_p \times (100 - P) + W_z \times (100 - Z) \]  

where \( E \) is the comprehensive score of the river network health status, \( W_f, W_p \) and \( W_z \) are the weights of natural environment [9, 14-16], human activities impact and risk effects; \( I, P \) and \( Z \) are the scores of each level of indicators. \( I, P \) and \( Z \) will be scored between 0 to 100 based on the evaluation of basic indices.

### Table 2. Scoring system of secondary river network health indicators.

| Secondary indicators | Current Status | Score | Secondary indicators | Current Status | Score |
|----------------------|---------------|-------|----------------------|---------------|-------|
| Water quality        | No contamination | 100 | Environmental budget per unit area | Increasing >200% | 100 |
|                      | Low contamination | 75 |                             | Increasing 100%~200% | 75 |
|                      | Medium contamination | 50 |                             | Increasing 50%~100% | 50 |
|                      | High contamination | 25 |                             | Increasing 25%~50% | 25 |
|                      | Severe contamination | 0 |                             | Increasing <25% | 0 |
| Ratio of Water Surface | ≥12% | 100 | Ratio of impermeable area | >65% | 100 |
|                      | 8-12% | 75 |                             | 50%~65% | 75 |
|                      | 6-8% | 50 |                             | 35%~50% | 50 |
|                      | 3-6% | 25 |                             | 20%~35% | 25 |
|                      | <3% | 0 |                             | ≤20% | 0 |
| Network complexity   | Increasing | 100 | Environmental flow rate | >90% days of year | 100 |
|                      | Decreasing ≤ 10% | 75 |                             | 70~90% days of year | 75 |
|                      | Decreasing 10%~30% | 50 |                             | 50~70% days of year | 50 |
|                      | Decreasing 30%~50% | 25 |                             | 30~50% days of year | 25 |
|                      | Decreasing >50% | 0 |                             | <30% days of year | 0 |
| GDP per unit area    | Growing >200% | 100 | Natural risk index | Increasing >30% | 100 |
|                      | Growing 100%~200% | 75 |                             | Increasing 10%~30% | 75 |
|                      | Growing 50%~100% | 50 |                             | Between -10%~10% | 50 |
|                      | Growing 25%~50% | 25 |                             | Decreasing 10%~30% | 25 |
|                      | Growing <25% | 0 |                             | Decreasing <30% | 0 |

*Note: Scoring of river numbers and basin dense are the same as network complexity. Scoring of population per unit area, pollution per unit area and water consumption per unit area are the same as GDP per unit area.

3. Case study

### 3.1. Overview

Water diversion projects have been constructed and operated since 2012 in Jiaxing river network, and since 2014 in Wenzhou river network, the river networks in these two cities are shown in Figure 2 [9-12]. In this study, both of them are selected as research objects. Recently, water quality monitoring experiments are executed in these two cities, the monitoring data are collected in this study to represent water quality and other flow characteristics, while the other statistics such as field population, economics and environmental budget are obtained by social statistical yearbook (2010-2018), environmental statistical handbook (2010-2018) and the river restoration report of these two typical
city river networks [10-13]. All of the collected data are then calculated and evaluated using the method in Table 1 in order to represent the river network health status [14-16].

![Figure 2. River network in both Jiaxing and Wenzhou cities.](image)

**Table 3.** Health status of Jiaxing river network before and after water diversion.

| Indicators                     | River network health status before water diversion | River network health status after water diversion |
|-------------------------------|---------------------------------------------------|--------------------------------------------------|
| **Main Target**               | **1st level indicator**                           | **2nd level indicator**                          | **Weight** | **Basic Score** | **2nd level score** | **1st level score** | **Overall** | **Basic Score** | **2nd level score** | **1st level score** | **Overall** |
| **Natural environment**       | Water quality 0.22                                | 25                                                | 5.5        | 46.8           | 50                  | 11                  |
|                               | Ratio of Water Surface 0.11                       | 75                                                | 8.25       |                | 75                  | 8.25                |
|                               | River numbers 0.11                                | 75                                                | 8.25       |                | 75                  | 8.25                |
|                               | Network complexity 0.22                           | 50                                                | 11         |                | 75                  | 16.5                |
|                               | Soil pollutant level 0.11                         | 25                                                | 2.75       |                | 50                  | 5.5                 |
|                               | Basin dense 0.22                                  | 50                                                | 11         |                | 50                  | 11                  |
| **River network health status**| GDP per unit area 0.51                            | 25                                                | 12.75      | 60.6           | 25                  | 12.75               |
|                               | Population per unit area 0.11                     | 25                                                | 2.75       |                | 25                  | 2.75                |
|                               | Pollution per unit area 0.06                      | 50                                                | 3          | 2               | 50                  | 3                   | 0.5               |
|                               | Water consumption 0.06                            | 50                                                | 3          |                | 25                  | 1.5                 |
|                               | Environmental budget per unit area 0.26           | -75                                               | -19.5      |                | -75                 | -19.5               |
| **Risk Effects**              | Ratio of impermeable 0.5                          | 75                                                | 37.5       | 62.5           | 75                  | 37.5                |
|                               | Environmental flow rate 0.25                      | 50                                                | 12.5       |                | 25                  | 6.25                | 50               |
|                               | Natural risk index 0.25                           | 50                                                | 12.5       |                | 25                  | 6.25                |
3.2. Evaluation results

The scoring criteria of all secondary indicators are shown in Table 2, which are evaluated with 0~100 points stepped by 25. According to the data and scoring criteria of the secondary indicators, the results of the river network health status before and after water diversion in Jiaxing and Wenzhou are shown in Table 3 and Table 4. The indicators and their weight are adjusted by previous researchers [12-16].

From Table 3 to Table 4, the improvements of the health status before and after water diversion are clearly shown in both Jiaxing and Wenzhou river networks. As shown in Table 3, for Jiaxing river network, several indicators such as water quality, soil pollutant, and network complexity have been greatly improved, which indeed reflect the advantages and benefits of the water diversion project in Jiaxing city. Similar improvements are shown in Table 4: the water diversion project in Wenzhou city also introduced better upstream flow to the plain river network, and eventually improved the health status of the river network in Wenzhou city.

Table 4. Health status of Wenzhou river network before and after water diversion.

| Indicators | River network health status before water diversion | River network health status after water diversion |
|------------|-----------------------------------------------|-----------------------------------------------|
|            | Weight | Basic Score | 2nd level | 3rd level | Overall | Weight | Basic Score | 2nd level | 3rd level | Overall |
| Natural environment (0.54) | | | | | | | | | |
| Water quality | 0.22 | 0 | 0 | | | | | | |
| River numbers | 0.11 | 75 | 8.25 | | | | | | |
| Network complexity | 0.22 | 50 | 11 | | | | | | |
| Soil pollutant level | 0.11 | 25 | 2.75 | | | | | | |
| Basin dense | 0.22 | 50 | 11 | | | | | | |
| River network health status | | | | | | | | | |
| GDP per unit area | 0.51 | 25 | 12.75 | | | | | | |
| Population per unit area | 0.11 | 25 | 2.75 | | | | | | |
| Pollution per unit area | 0.06 | 100 | 6 | | | | | | |
| Water consumption | 0.06 | 75 | 4.5 | | | | | | |
| Environmental budget per | 0.26 | -50 | -13 | | | | | | |
| Human activities impact (0.30) | | | | | | | | | |
| Risk effects (0.16) | | | | | | | | | |
| Ratio of impermeable | 0.5 | 100 | 50 | | | | | | |
| Environmental flow rate | 0.25 | 25 | 6.25 | | | | | | |
| Natural risk index | 0.25 | 75 | 18.75 | | | | | | |

5
Figure 3. Comparison of river network health status between Jiaxing and Wenzhou considering water diversion project (a) Natural environment, (b) Human activities impact, (c) Risk effects.
4. Discussions and analysis
It is also necessary to compare and analyze the evaluation results of both Jiaxing river network and
Wenzhou river network to reveal the similarity and difference between them. In this study, the
comparison of the river network health status is made considering the data collected after the water
diversion in these two cities. According to the statistical data, the water surface rate of Jiaxing reaches
8.83%, while it is only 5.3% in Wenzhou. From the point view of water quality, the overall water
quality improvement of Jiaxing is also better than in Wenzhou. Taking the monitoring data in 2016 as
an example, the overall water quality of Jiaxing is in better condition, thus, it is scored more than
Wenzhou. Moreover, the better water quality in Jiaxing is also attributed to the sewage interception
rate. According to the statistics of environmental protection data, the sewage interception rate of
Wenzhou is 58%, while it is 76% in Jiaxing, which leads to the better water quality in the Jiaxing river
network.

As shown in Eq. (1), the Human activity impact factor is a negative impact factor. The higher the
score, the lower the health level of the watershed, and vice versa. From Figure 3(b), Jiaxing and
Wenzhou scored the same in terms of environmental budget per unit area, population per unit area and
GDP per unit area, which shows that both Jiaxing and Wenzhou have made great efforts on increasing
the economics and environment. Indeed, the environmental budget of Wenzhou city and Jiaxing city
reaches 67.43 million Yuan and 33.6 million Yuan, respectively. From 2010 to 2015, the water
consumption per unit area of Wenzhou increased by 26%, the solid waste discharge increased by 27%,
while the water consumption per unit area in Jiaxing increased by 0.9% and the solid waste discharge
increased by 13% in the same period, which reflects the higher energy consumption and pollution
industries in Wenzhou.

From Figure 3(c), firstly, when considering environmental flow rate, Jiaxing is able to divert the
high-quality water source from the Taihu Lake theoretically. However, it is difficult to regulate and
control to divert water from the Taihu Lake due to the natural flow direction of the Jiaxing river
network. While for Wenzhou, although the high-quality water sources are insufficient, the higher
operation guarantee rate of hydraulic engineering facilities lead to a higher score. Secondly, according
to previous research, the probability of disasters in Wenzhou and the losses caused by disasters are
higher than in Jiaxing. Therefore, Wenzhou scored higher on environmental flow rate than Jiaxing,
while Jiaxing scored better on the other two secondary indicators.

In summary, the health status of the Jiaxing river network after the water diversion project
operation is 70.5, and it is 58.2 in the Wenzhou river network. Jiaxing scored better than Wenzhou in
seven secondary indicators such as water quality, ratio of water surface, water consumption per unit area,
pollution per unit area, ratio of impermeable area, environmental flow rate and natural risk index.
Hence, although both cities have constructed water diversion project to improve the river network
health, the health status of Jiaxing river network is significantly better than the Wenzhou river network.

5. Conclusions
The main factors affecting the regional water environment of the river network are focused in this
study, which includes regional population and economy, the amount of pollution entering the river and
the condition of water resources, etc. Moreover, since the water diversion projects have been
constructed and operated in lots of Chinese cities, the health status of river network before and after
water diversion has been considered. The Jiaxing river network and the Wenzhou river network are
selected as typical examples, the health status of these two river networks are carried out, evaluation
results reflect the differences between these two regions and indicate that the selected evaluation
system and its evaluation results are convincing. Future work can be extended to the other coastal
cities in China to show the advantages of water diversion projects especially in river network water
quality improvement, and help the city government to construct and operate the water diversion
project based on this decision-making system.
Acknowledgments
This research was supported in part by the National Natural Science Foundation of China (51709237), the science and technology plan projects of Zhejiang Province(2018F10028), and the Zhejiang water conservancy science and technology plan projects(RC1823).

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