

Article

Study on the Nexus Effects of Water Conservation, Pollutant Control and Carbon Emissions of a Multi-Source Water Supply System

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Abstract

Water scarcity and the greenhouse effect are two global issues that have attracted researchers' attentions for decades. A multi-source water supply system has been established in a typical Chinese city experiencing a water shortage—namely, Yiwu City—in order to solve the city's water shortage problem. Our study focuses on the integrated analysis of water conservation, pollutant control and carbon emissions in the multi-source water supply system, and a comprehensive model is derived in order to simulate these three factors together. It is confirmed that the multi-source water supply system has significantly improved the efficiency of local water allocation and the water supply guarantee rate, considering that the replacement rate of reclaimed water varies from 0% to 50%. It is anticipated that water conservation and pollutant control can be achieved simultaneously in Yiwu City, although accomplishing these goals and also reducing carbon emissions is difficult due to the significant impact of local topography and geomorphology. When the proportion of reclaimed water used in landscape ecological water increases from 0 to 50%, COD emissions decrease by 656 t/a, NH₃-N emissions decrease by 11 t/a, and the corresponding carbon emissions increase by 0.096×10^4 t CO₂/a. The simulation results of this study provide important references for addressing water shortage issues and achieving carbon emission reduction goals in Yiwu City and other similar cities experiencing water shortages in the future.

Keywords: water conservation; pollutant control; carbon emissions; nexus effects; multi-source water supply



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1. Introduction

Water scarcity and the greenhouse effect are two key issues that have attracted the attention of previous researchers [1–4]. In order to alleviate local water scarcity [5,6], multi-source water supply systems with multilevel water quality have been widely accepted as a novel local water management tool around the world. These systems can enhance the utilization efficiency of local water supplies by allocating different water sources for different purposes, such as for agricultural and industrial use [4–9]. Additionally, reducing sewage discharge and alleviating pollutant emissions can both be achieved by utilizing a multi-source water supply system. As a typical city experiencing a water shortage [7–11],

Yiwu City requires a multi-source water supply to ensure local water security, which is critical for urban residents and local industry. In this study, the nexus effects connecting water conservation, pollutant control, and carbon emissions are evaluated and analyzed. Our evaluation will not only be helpful for local water resource management, but will also demonstrate the advantages of these supply systems in improving both the local environment and economy over the next decades [12–16].

The nexus effects of water conservation, pollutant control and carbon emissions from a multi-source water supply system represent a vital research topic, as water environment conservation and carbon emission reduction are critical issues around the world [7,12,15]. As indicated by recent studies, new computational methods such as the finite concentration method (FCM) can simulate carbon monoxide and carbon dioxide in a variety of different environmental situations [14–20]. Based on these developments, a numerical model is derived in this study. Through the numerical simulation and analysis of the water conservation, pollutant control and carbon emissions of a multi-source water supply system in Yiwu City, we demonstrate that the mutual coordination of water conservation and pollutant control can be achieved simultaneously through the optimized allocation of different water sources [5–9,21–24]. However, the coordination of all three main factors, namely water conservation, pollutant control and carbon emission reduction, is infeasible to achieve synchronously due to the local terrain, topography and spatial layout of water sources, all of which have significant impacts on carbon emission intensity [6,15,19]. Additionally, the local carbon emission intensities of the water supply system's sources can be ranked from small to large based on different levels of high-quality water source replacement. General water sources contribute the least carbon emissions; high-quality water sources, such as reservoir water, contribute medium carbon emissions; and reclaimed water sources lead to the highest carbon emissions [12–18]. On the other hand, it is anticipated that utilizing more reclaimed water will lead to better water conservation and pollutant control despite the greater carbon emission scenario, as indicated by previous research [9–12].

2. Materials and Methods

2.1. Study Area

Yiwu City, located in the central part of Zhejiang Province, is close to the east coast of China. Due to its dense population and highly developed economy, the imbalance between the city's water demand and supply has become increasingly prominent. Efforts have been made to overcome these water supply barriers: the city's government constructed a local multi-source water supply system in 2010 in order to optimize different water resources for various purposes. Specifically, high-quality water resources are used for urban residents' drinking water, while general river water is used in industrial processes and contributes to water in rivers and lakes. Additionally, reclaimed water is widely used in toilet flushing, road cleaning and small- and medium-sized rivers. Indeed, Yiwu City has constructed the most efficient water supply system in the eastern area of China, demonstrating its effective function in promoting optimal local water usage over the past decades.

2.2. Methodology

Firstly, water-saving refers to a reduction in the use of high-quality reservoir water and river water by local residents due to the increasing use of reclaimed water from sewage treatment plants, which is recognized as a good alternative to high-quality water [18–23]. Secondly, pollutant control refers to the use of reclaimed water, which reduces the amount of wastewater discharge and improves the water quality of the river network in Yiwu City [20–24]. Thirdly, carbon emission effects refer to the carbon dioxide emissions from

the local multi-source water supply system, which is also related to the local water demand and the local water supply capacity [20–25].

Figure 1 shows that the relationship between water conservation, pollutant control and carbon emissions is complex. The nexus effects among them are the focus of this study due to the uncertainty and substitutability of local water demand. As indicated in Figure 1, various kinds of local water consumers participate in the complex local multi-source water supply system [26–32].

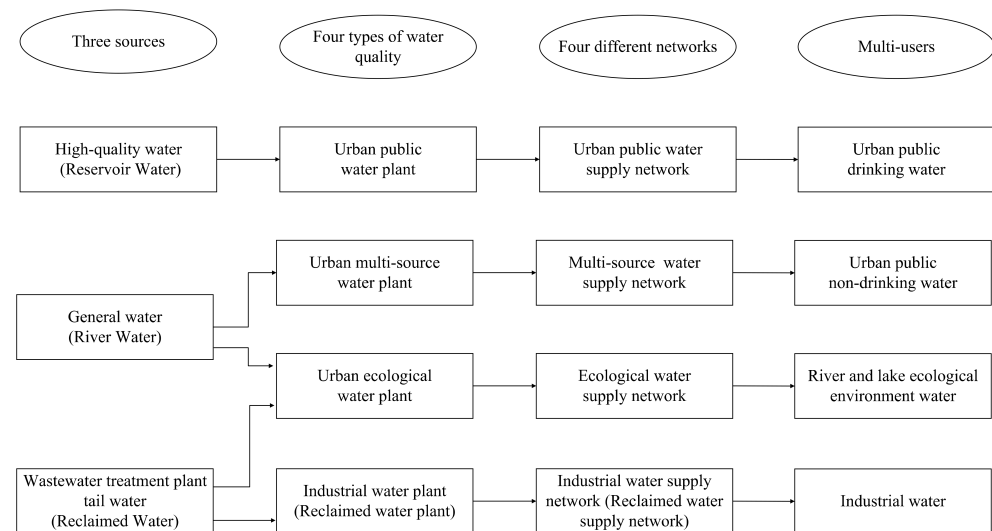


Figure 1. The multi-source water supply system in Yiwu City.

In order to clarify the relationships between water conservation, pollutant control and carbon emissions and their nexus effects in the multi-source water supply system in Yiwu City, a numerical model combining local water demand and supply, pollutant discharge and carbon emission intensity is developed in this study. It is assumed that the capacity of the hydraulic control structures in Yiwu City will not change during their life cycle, remaining a constant during the simulation [24–26].

(1) General equations

First, a water supply function is introduced to determine the maximum water supply capacity of the local multi-source water supply system, given as [6,22]

$$f_1 = \max \sum_{i=1}^2 [W_i^{\max} - W_i] \quad (1)$$

where $W_i^{\max}$ and W_i are the maximum water supply capacity (m^3/s) and the actual water supply capacity (m^3/s), respectively. The physical meaning of Equation (1) is to ensure that the maximum water supply capacity will not exceed the actual water supply capacity. Hence, the limitation of the local water supply capacity is confirmed as the basic condition of the general model.

Second, a pollutant control function is used to ensure that the inflow of major pollutants, which is represented by chemical oxygen demand (COD) and ammonia nitrogen ($\text{NH}_3\text{-N}$), will not exceed the pollutant carrying capacity of the local rivers in Yiwu City. The pollutant control function is given as

$$f_2 = PQ_j^0 - PQ_j \geq 0 \quad (2)$$

where PQ is the amount of the specific pollutant (t/a). The superscript 0 represents the pollutant carrying capacity for COD and $\text{NH}_3\text{-N}$, respectively.

Third, a carbon emissions function is introduced to calculate the total carbon emissions from the multi-source water supply system, given as

$$f_3 = \min \sum_{i=1}^3 \sum_{k=1}^4 w_{ik} \times \alpha_{ik} \quad (3)$$

where α_{ik} is the carbon emission intensity (t/m^3) of the different water consumers. Additionally, the energy and material consumption of the entire social water cycle process, including the water source, water supply, water usage and drainage, are calculated using Equations (2) and (3) [22,24–29].

(2) Constraints

(1) The local water guarantee rate is given as

$$p_k \geq p_k^0 \quad (4)$$

where p_k is the guarantee rate (%), and the superscript 0 indicates the current status.

(2) The balance between local water supply and demand is given as

$$W_i = \sum_{k=1} w_{ik} / (1 - \beta_k) \quad (5)$$

$$W_{wo} = \sum_{i=1} \sum_{k=1} w_{ik} \times \delta_0 \quad (6)$$

where w_{ik} is the water demand of different water consumers, β is the water-saving coefficient, and δ is the water consumption coefficient. The relationship between the local water demand and water supply is calculated based on Equations (4)–(6).

(3) The water demand constraint condition is set to represent the total water volume allocated to different industries. In this study, it basically describes the limits of the water demand and water supply during the simulation [28–31].

(4) The pollutant control condition represents local pollutants discharged into the river network, given as

$$Q_j = A \times \varphi_{1j} + W_{wo}^{out} \times \varphi_{2j} \quad (7)$$

where A is the local area (km^2), and the other symbols are the same as above.

(5) The water quantity condition is given as

$$WQ_i \leq WQ_i^{\max} \quad (8)$$

where WQ is the water quantity (10^4 m^3), and $WQ_{\max}$ is the local maximum water quantity (10^4 m^3).

(6) The maximum local multi-source water supply capacity and the local water demand are both considered in this study, and are introduced to guarantee that the configured water volume of all the water supply projects will not exceed their maximum water supply capacity, as shown in Equations (7) and (8). A non-negative constraint is additionally included in the numerical model [32–37].

2.3. Simulation Algorithm

The numerical model of the local multi-source water supply system is developed based on the algorithm shown in Figure 2. A i7 CPU and 32 GB memory Work Station is used in this study to solve the model. The verification data used in this model were

obtained from the local government statistical yearbook for the years 2019 to 2024 [35]. The model algorithm is shown in Figure 2, including the input of the parameters, the initial conditions and the constraints. The model is used to calculate the nexus effects of water conservation, pollutant control and carbon emissions together. If the model evaluation criteria are satisfied, the final allocation scheme will be selected; otherwise, the model will recalculate until all the criteria are met.

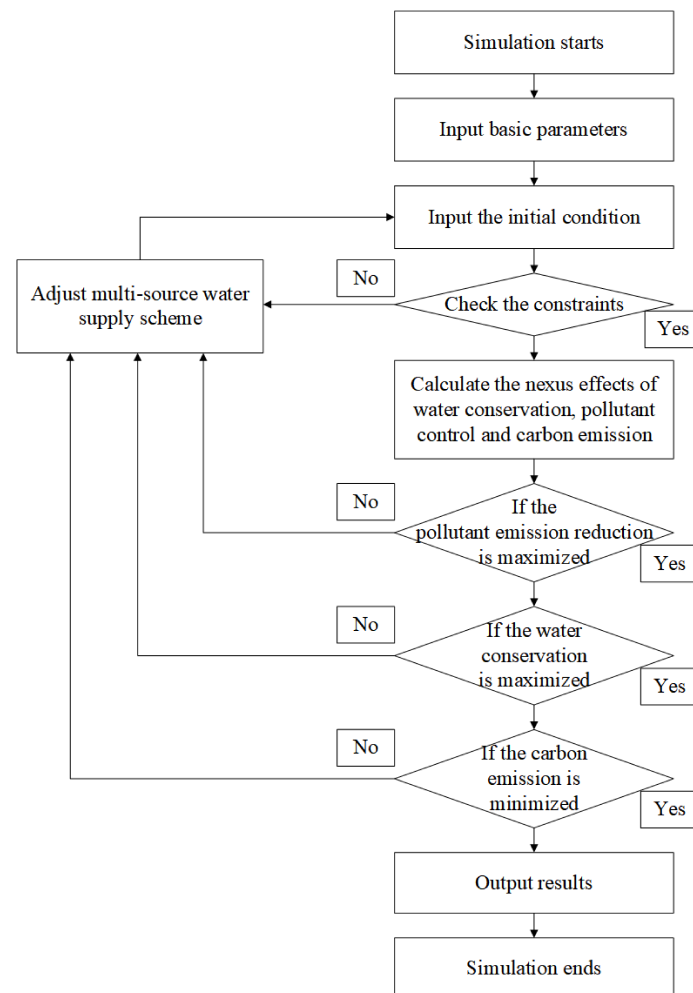


Figure 2. Model algorithm.

3. Simulation Characteristics

This study utilized a 95% hydrological frequency during the simulation based on local hydrological and meteorological conditions [31]. The year 2025 was selected as the current year, and the year 2030 was selected as the planning year. The corresponding water volumes from different water sources are shown in Table 1 and Figure 3. The predicted results for water consumption at both the current-year level and planning-year level are shown in Table 2, while the components of different types of water consumption are shown in Figures 4 and 5 for the different years, respectively.

Table 1. Multi-source water supply capacity in Yiwu City in 2025.

Month	Volume (10 ⁶ m ³)		
	Reservoir Water	Diversion Project	General River Water
Jan	3.1	0	38.9
Feb	5.3	0	68.4
Mar	10.5	0	140.7
Apr	10.9	0	145.1
May	10.5	0	140.7
Jun	17.4	0	234.3
Jul	7.4	0	89.4
Aug	3.8	0	33.8
Sep	3.7	0	36
Oct	2.3	0	26.5
Nov	2.3	0	27.2
Dec	2.3	0	27.2
Total	79.3	0	1008.3

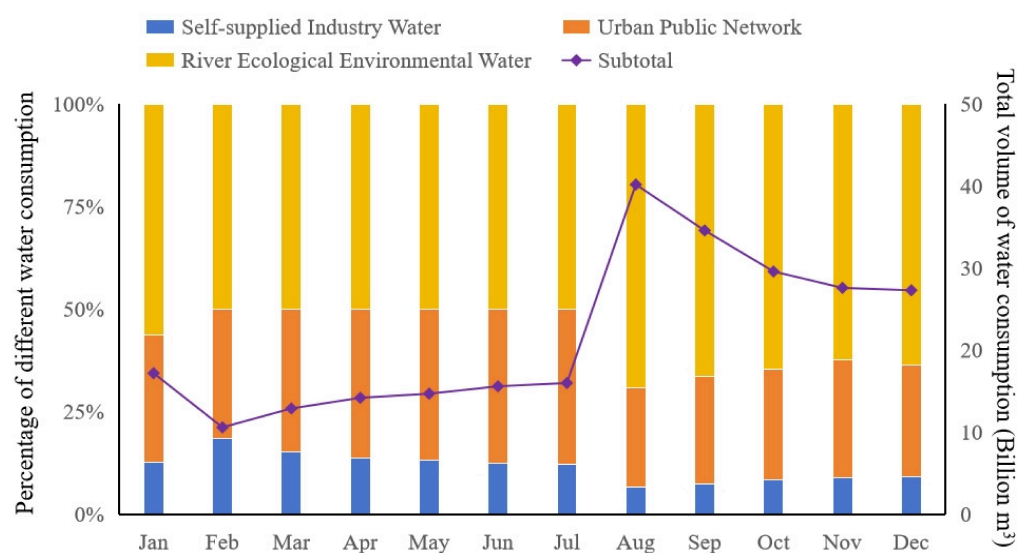
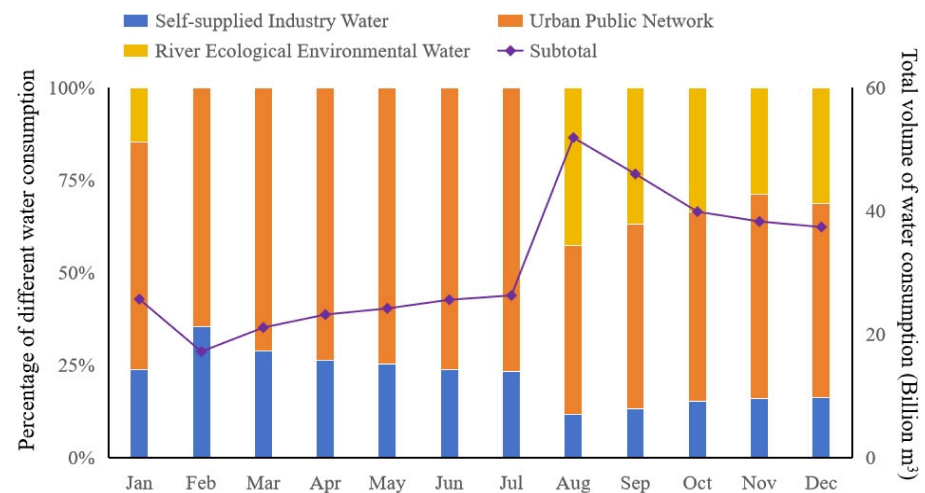
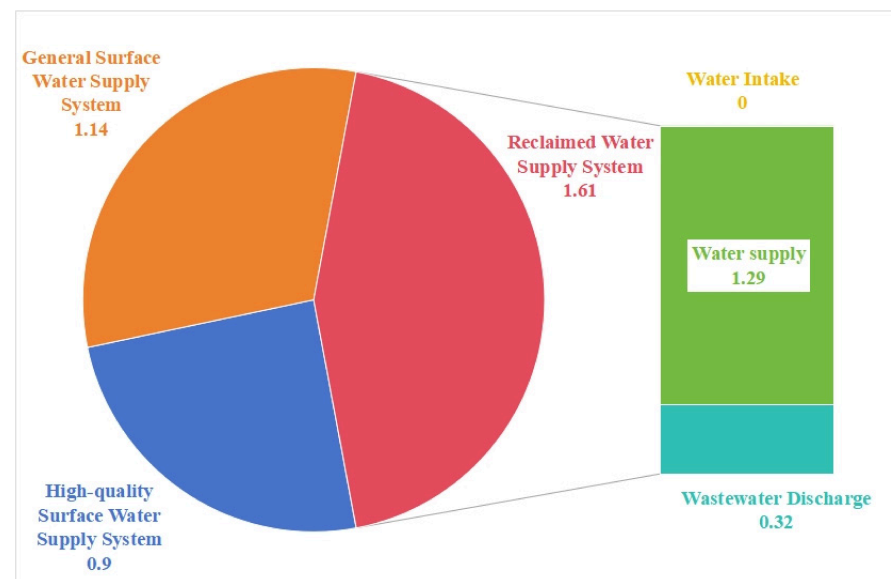
**Figure 3.** Water consumption at current-year level (2025) in Yiwu City.

Table 2. Simulation results of water demand for different years in Yiwu City.

Month	Current-Year Level (2025, 10 ⁶ m ³)				Planning-Year Level (2030, 10 ⁶ m ³)			
	Self-Supplied Industry	Urban Public Network	River Ecological Environment	Total	Self-Supplied Industry	Urban Public Pipeline Network	River Ecological Environment	Total
Jan	3.9	9.5	3.8	17.2	6.1	15.8	3.8	25.7
Feb	3.9	6.7	0	10.6	6.1	11.1	0	17.2
Mar	3.9	9	0	12.9	6.1	15	0	21.1
Apr	3.9	10.3	0	14.2	6.1	17.1	0	23.2
May	3.9	10.8	0	14.7	6.1	18.1	0	24.2
Jun	3.9	11.7	0	15.6	6.1	19.5	0	25.6
Jul	3.9	12.1	0	16	6.1	20.2	0	26.3
Aug	3.9	14.1	22.2	40.2	6.1	23.6	22.2	51.9
Sep	3.9	13.7	17	34.6	6.1	22.9	17	46
Oct	3.9	12.3	13.4	29.6	6.1	20.4	13.4	39.9
Nov	3.9	12.7	11	27.6	6.1	21.2	11	38.3
Dec	3.9	11.7	11.7	27.3	6.1	19.6	11.7	37.4
Total	46.6	134.6	79.1	260.3	73.4	224.6	79.1	377.1

**Figure 4.** Water consumption during planning year (2030) in Yiwu City.**Figure 5.** Components of the multi-source water supply system in Yiwu City.

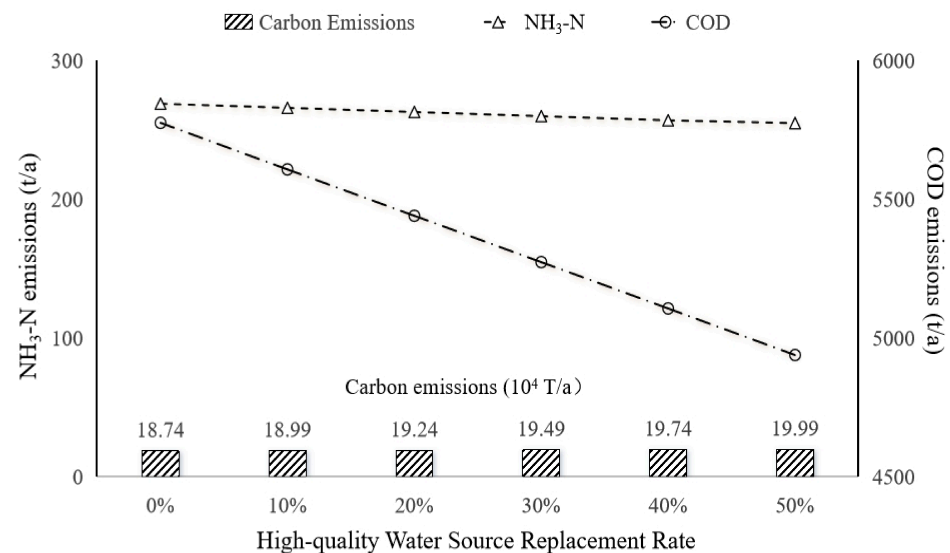


Figure 6. Analysis of water conservation, pollutant control and carbon emission nexus effects at the current-year level (2025).

The simulation model for the local multi-source water supply system was developed based on the simulation algorithm shown in Figure 2 in Section 2.2, while the relevant parameters used during the present simulation are shown in Table 5.

Table 5. Determination of the relevant model parameters.

Indicator	Unit	Value	Indicator Description
Water supply capacity of high-quality surface water	10 ⁴ t/d	74	Includes the capacity of urban public water plants and their supporting pipe networks
Water supply capacity of ordinary surface water	10 ⁴ t/d	36	Includes the capacity of urban water plants with different water qualities and their supporting pipe networks and the capacity of urban ecological water plants and their supporting pipe networks
Water supply capacity of sewage treatment plants	10 ⁴ t/d	17.5	Includes the capacity of industrial water plants and their supporting pipe networks and the capacity of ecological water plants and their supporting pipe networks
Upper limit of industrial water replacement rate	%	57	Upper limit of industrial water supply from reclaimed water and river water
Upper limit of urban public water replacement rate	%	40	Upper limit of urban public water supply from reclaimed water and river water
Leakage rate of various water supply pipelines	%	12	Implemented in accordance with the provisions of existing policy documents
Comprehensive coefficient of sewage treatment plants	%	0.80	Deducts the water loss during urban sewage collection and treatment processes
Rainwater catchment area of rivers and lakes	km ²	826.1	Obtained from topographic maps according to the overall water resources plan of Yiwu City

4. Discussion

The results of the above simulation model of the multi-source water supply system for both the current year and planning year for Yiwu City are shown in Tables 6 and 7. Generally, the high-quality water source replacement rate was fixed at 30% and 50% during

the simulation for the recommended plan. Further analysis is focused on the nexus effects of water conservation, pollutant control and carbon emissions on the local environment and ecology. The analyzed results are shown in Tables 8 and 9.

Table 6. Simulation results of multi-source water supply configuration for Yiwu City in 2025.

High-Quality Water Source Replacement Rate (%)		0	10	20	30	40	50
Balance Water Volume of Different Water Sources (10^8 m^3)	High-Quality Water	0.35	0.48	0.62	0.75	0.89	1.02
	Ordinary Water	9.33	9.26	9.19	9.13	9.06	8.99
	Reclaimed Water	0.95	0.88	0.81	0.75	0.68	0.61
Water Shortage of Different Water Users (10^8 m^3)	Industrial Water Use	0	0	0	0	0	0
	Urban Water Use	0	0	0	0	0	0
	Landscape Ecology	0	0	0	0	0	0
Carbon Emissions ($10^4 \text{ t.CO}_2/\text{a}$)	High-Quality Water	12.11	10.90	9.69	8.48	7.27	6.06
	Ordinary Water	4.23	4.76	5.29	5.82	6.35	6.89
	Reclaimed Water	2.40	3.33	4.26	5.19	6.12	7.04
	Total	18.74	18.99	19.24	19.49	19.74	19.99

Table 7. Simulation results of multi-source water supply configuration for Yiwu City in 2030.

High-Quality Water Source Replacement Rate (%)		0	10	20	30	40	50
Balance Water Volume of Different Water Sources (10^8 m^3)	High-Quality Water	0	0	0	0.13	0.35	0.57
	Ordinary Water	9.06	8.95	8.84	8.73	8.61	8.50
	Reclaimed Water	1.88	1.77	1.65	1.54	1.43	1.32
Water Shortage of Different Water Users (10^8 m^3)	Industrial Water Use	0	0	0	0	0	0
	Urban Water Use	0.55	0.33	0.10	0	0	0
	Landscape Ecology	0	0	0	0	0	0
Carbon Emissions ($10^4 \text{ t CO}_2/\text{a}$)	High-Quality Water	15.26	15.26	15.26	14.10	12.12	10.10
	Ordinary Water	6.31	7.20	8.09	8.97	9.86	10.75
	Reclaimed Water	2.40	3.95	5.50	7.05	8.60	10.15
	Total	23.97	26.40	28.84	30.12	30.58	31.00

As shown in Table 6 and Figure 6, when considering the current-year level, every simulation of Yiwu City was able to achieve a balance between water supply and demand. However, differences are still observed between cases in terms of the three important indicators: namely, the total volume of water conservation, the total amount of pollutant control and the total carbon emissions. With the increase in the high-quality water source replacement rate from 0% to 50%, the proportion of high-quality water, general water and reclaimed water varied from 3.3:87.8:8.9 to 9.6:84.7:8.7, and the total amount of COD and $\text{NH}_3\text{-N}$ decreased by 837 t/a and 14 t/a, respectively, while the corresponding carbon emissions increased by $1.25 \times 10^4 \text{ t CO}_2/\text{a}$. The COD and $\text{NH}_3\text{-N}$ emissions decreased by 167.4 t/a and 2.8 t/a, and the corresponding carbon emissions increased by $0.25 \times 10^4 \text{ t CO}_2/\text{a}$ for every 10% high-quality water replacement rate increment.

Table 6 shows that pollutant emissions generally decrease, while carbon emissions increase as the replacement rate rises in 2025. This trade-off is observed because the better efficiency of the sewage treatment plant results in lower pollutant emissions, though the energy consumption is much higher. The carbon emissions will eventually increase along with the energy consumption; hence, the results shown in Table 6 are also acceptable.

Table 8. Sensitivity analysis of reclaimed water utilization for Yiwu City in 2025.

High-Quality Water Source Replacement Rate (%)		0	10	20	30	40	50
Balance Water Volume of Different Water Sources (10 ⁸ m ³)	High-Quality Water	0.13	0.13	0.13	0.13	0.13	0.13
	Ordinary Water	8.39	8.46	8.53	8.59	8.66	8.73
	Reclaimed Water	1.21	1.27	1.34	1.41	1.47	1.54
Water Shortage of Different Water Users (10 ⁸ m ³)	Industrial Water Use	0	0	0	0	0	0
	Urban Water Use	0.668	0.5332	0.399	0.2638	0.1291	0
	Landscape Ecology	0	0	0	0	0	0
Point Source Emissions (t/a)	COD	1349	1516	1683	1851	2018	2186
	NH ₃ -N	22.79	25.62	28.45	31.27	34.1	36.93
Non-Point Source Emissions (t/a)	COD	4295	4295	4295	4295	4295	4295
	NH ₃ -N	244	244	244	244	244	244
Total Emissions (t/a)	COD	5643	5811	5978	6146	6313	6480
	NH ₃ -N	266	269	272	275	278	281
Remarks: Ordinary water and reclaimed water account for 50% of ecological water use.							

Table 9. Sensitivity analysis of reclaimed water utilization for Yiwu City in 2030.

High-Quality Water Source Replacement Rate (%)		0	10	20	30	40	50
Balance Water Volume of Different Water Sources (10 ⁸ m ³)	High-Quality Water	0.13	0.13	0.13	0.13	0.13	0.13
	Ordinary Water	8.33	8.41	8.49	8.57	8.65	8.73
	Reclaimed Water	1.94	1.86	1.78	1.70	1.62	1.54
Water Shortage of Different Water Users (10 ⁸ m ³)	Industrial Water Use	0	0	0	0	0	0
	Urban Water Use	0	0	0	0	0	0
	Landscape Ecology	0	0	0	0	0	0
Point Source Emissions (t/a)	COD	2841	2710	2579	2448	2317	2186
	NH ₃ -N	48	46	44	41	39	37
Non-Point Source Emissions (t/a)	COD	4295	4295	4295	4295	4295	4295
	NH ₃ -N	244	244	244	244	244	244
Total Emissions (t/a)	COD	7136	7005	6874	6743	6612	6480
	NH ₃ -N	292	289	287	285	283	281
Remarks: Ordinary water and reclaimed water account for 50% of ecological water use.							

In the case of the planning-year level shown in Table 7 and Figure 7, representing a continuous rise in social and economic water demand in Yiwu City, it is quite difficult to achieve a balance between water supply and demand. The replacement rate of high-quality water sources had to be above 30% in order to reach a balance between the local water supply and demand; otherwise, water shortage problems will appear due to the insufficient local water supply capacity.

Similarly, when the replacement rate of high-quality water sources increased from 0 to 50%, the proportion of high-quality water, general water and reclaimed water varied from 0:82.8:17.2 to 5.5:81.8:12.7. Meanwhile, the total amounts of COD and NH₃-N decreased by 1395 t/a and 24 t/a, respectively, and the corresponding carbon emissions increased by 7.03×10^4 t CO₂/a. The COD and NH₃-N emissions decreased by 279 t/a and 4.8 t/a, and the corresponding carbon emissions increased by 1.406×10^4 t CO₂/a for every 10% high-quality water replacement rate increment.

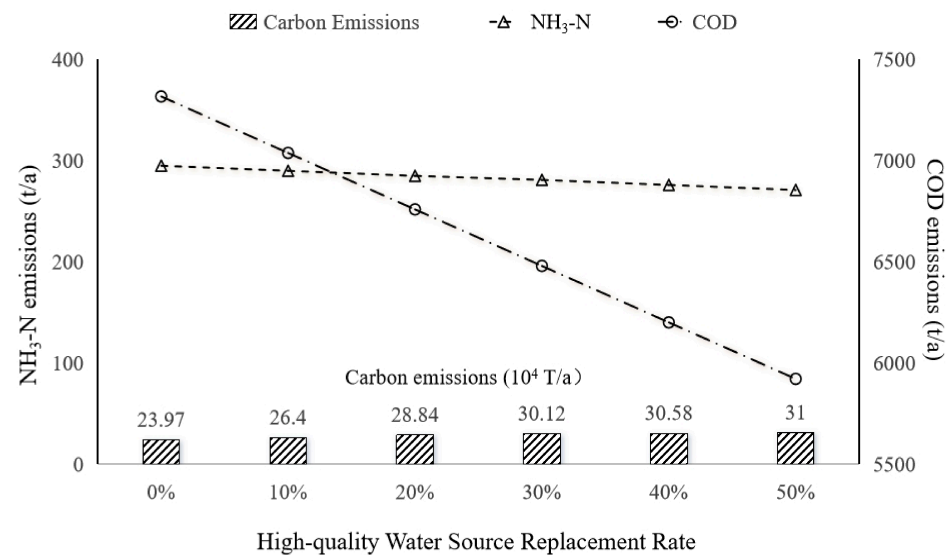


Figure 7. Analysis of water conservation, pollutant control and carbon emission nexus effects for the planning year (2030).

Under the conditions of the planning year, sensitivity analysis among all types of water sources also shows the importance of local pollutant control and carbon emissions, as can be seen in Tables 8 and 9 and Figures 8 and 9. As shown in Table 8 and Figure 8, during the year 2025, the local water supply will become insufficient compared with the local household water demand, especially for high-quality water. As predicted by the numerical model, a balance between local water supply and demand will be reached only if a 50% replacement rate of high-quality water sources is achieved. Additionally, the corresponding carbon emissions decrease by 1.406×10^4 t CO₂/a with every 10% increment in the reclaimed water source utilization rate. Moreover, COD emissions increase by 279 t/a, and NH₃-N emissions increase by 3.0 t/a for every 10% increment in reclaimed water utilization. It can be concluded that, because of the temporal and spatial distribution of different water sources in Yiwu City, a water shortage problem will occur, especially in urban areas, and efforts should be made to enhance the utilization of reclaimed water.

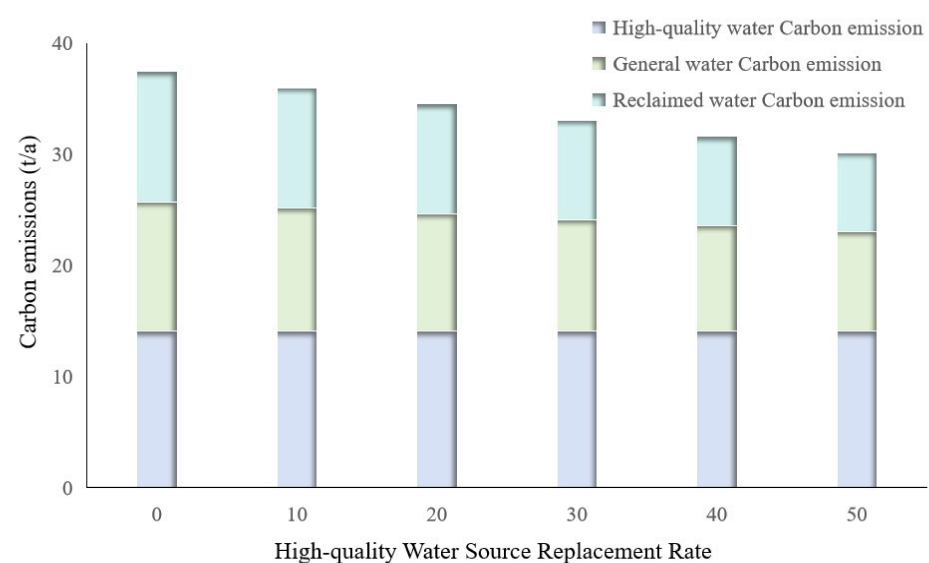


Figure 8. Sensitivity analysis of carbon emission intensity for Yiwu City in 2025.

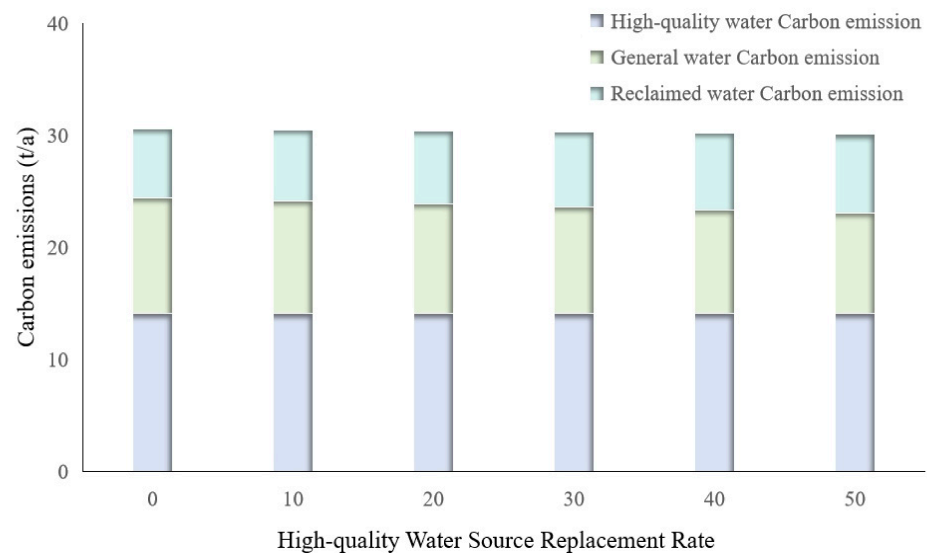


Figure 9. Sensitivity analysis of carbon emission intensity for Yiwu City in 2030.

As shown in Table 9 and Figure 9, during the year 2030, the water conservation, pollutant control and carbon emission nexus effects are also apparent, and are similar to the local multi-source water supply system for the year 2025. Indeed, when the proportion of reclaimed water used in landscape ecological water increases from 0 to 50%, COD emissions decrease by 656 t/a, $\text{NH}_3\text{-N}$ emissions decrease by 11 t/a and corresponding carbon emissions increase by $0.096 \times 10^4 \text{ t CO}_2/\text{a}$.

Tables 8 and 9 demonstrate the sensitivity of the utilization of reclaimed water for the multi-source system in Yiwu City. In order to satisfy the local water demand, with the increase in the balanced total volume of reclaimed water from $1.21 \times 10^8 \text{ m}^3$ to $1.54 \times 10^8 \text{ m}^3$, the point source emissions of COD increase from 1349 t/a to 2186 t/a. Conversely, when the total balanced volume of reclaimed water usage reduces from $1.94 \times 10^8 \text{ m}^3$ to $1.54 \times 10^8 \text{ m}^3$, the point source emissions of COD decrease from 2841 t/a to 2186 t/a. Similar variations are obtained when considering the $\text{NH}_3\text{-N}$ point source emissions. In summary, since Yiwu City suffers from a serious water shortage problem, a 50% replacement rate of reclaimed water is required to satisfy the local water demand, which will lead to higher pollutant emissions.

5. Conclusions

In this study, we focused on the integrated analysis of water conservation, pollutant control and carbon emissions in a multi-source water supply system. A comprehensive model was constructed in order to simulate these three factors together, along with factors related to local sustainability, socio-economic and scientific progress and integrated approaches to sustainable development. Attention was also paid to the multi-source supply system in Yiwu City, which has three different water sources with various types of water qualities. A typical carbon emission intensity model for the life cycle of the multi-source water supply system was also established in this study in order to calculate carbon emissions from the local water supply. Based on the field monitoring and data analysis, the nexus effects of the multi-source water supply system in Yiwu City were evaluated.

The multi-source water supply system proved to be effective in improving both the efficiency and the guarantee rate of local social water circulation. For the planning year, the shortage of high-quality water sources will increase from a gap of 55 million cubic meters to an even greater high-quality water deficit. The utilization of reclaimed water and general river water for social and industrial applications will reach 163 million cubic

meters, and the replacement rate of high-quality water resources will exceed 30%. The discharge of local wastewater will be significantly reduced due to the utilization of large amounts of reclaimed water. Finally, a nearly 95% guarantee rate for the local household water demand will be achieved, along with a 90% guarantee rate for local industrial and agricultural water, which is sufficient and critical for local households and governments. The present model is also useful for cities affected by water shortage problems around the world, and can help resolve the contradictions between reclaimed water utilization, pollutant reduction, carbon emissions and local sustainable development. The nexus effects of water conservation, pollutant control and carbon emissions for the multi-source water supply system can be calculated and analyzed based on local data and the new derived numerical model, and the multi-source water supply system and reclaimed water have both been proven beneficial for those cities in the future.

In summary, we have identified that carbon emission intensity is significantly affected by domestic topography, geomorphology and the spatial layout of water sources. Future studies are recommended to focus on multi-water source spatial configurations, and the numerical model has been proven as a useful tool for simulating the nexus effects of water conservation, pollutant control and carbon emissions based on the different water demand requirements of the multi-source water supply system. Moreover, many new methods, including creator variable machines (CVMs), high-correlated variable creator machines (HCVCM), stronger variable creator machines (SVCMS), modified stronger variable creator machines (MSVCMs) and dynamic selecting machines (DSMs), have been created and presented between 2021 and 2025 [36–39]. These methods are strongly applicable for studying the nexus effects of water conservation, pollutant control and carbon emissions in a multi-source water supply system, and they can also be combined with other methods, such as ML, DP, GEP and the regression method, in an ensemble or hybrid model to improve both the accuracy and efficiency of the simulation results.

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