Assessment of sustainable water management for rapidly developing urban regions in Guangzhou City, China

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Abstract The Shawan River will be the focal point in the development of the Panyu District, the southern-most district of Guangzhou City in the Guangdong Province of South China. In this research, through the use of two scenarios, the future water quality of the Shawan River was predicted with relation to changes in the water quantity utilized to fuel industrial and domestic development. The worst-case scenario used, simulated the situation if no wastewater treatment was employed, and the best-case scenario simulated the situation if 90% of the pollution load was removed. The period of simulation was for the years 2020 and 2050. Three flowrates were used in the evaluation, those of: the 90% probability of the month of lowest flow (37.2 m^3/s); and the range of flowrates within the low flow period, that is, the dry season from November to February (307 and 432 m^3/s). Subsequently, two countermeasures (industrial and domestic water savings) – sustainable initiatives – were nested within the two scenarios to ascertain improvements in water quality as a direct result of reduction in water quantity used. The industrial water saving countermeasure showed the greatest improvement in water quality. For the 90% probability of lowest flow for the worst-case scenario, this countermeasure equated to a 63% decrease in BOD. For the low flow period flowrates the background concentration of pollutants was more influential than improvements imparted by the countermeasures to the future predicted water quality. It was recommended that industrial countermeasures be used that take into account water saving, water recycling, the use of brackish water for cooling, and the implementation of economic pricing initiatives. Also that inter-district governmental policy initiatives be introduced to prevent upstream pollution from influencing downstream proposals, further enhancing sustainable water management of the Shawan River.

Keywords China; Guangzhou City; Panyu District; Shawan River; water quality; water quantity; sustainable initiatives

Introduction

China falls into the category of a developing nation and has over the past several decades started on the road to industrialization. However, in the case of the Province of Guangdong in the south of China, with its provincial capital of Guangzhou situated at the top of the Pearl River Delta system, this economic growth has been very rapid. Since the introduction of the open door economic policy in the early 1980s, China and in particular Guangdong Province is facing many environmental problems as a result of these booming economic conditions.

The newly included area of Panyu (located directly south of Guangzhou) has entered into a very rapid phase of industrial and residential development. In December 2000 the Central People's Congress of Beijing approved a development plan to transform the Panyu District into a new industrial and domestic platform for the city of Guangzhou to be completed over the next fifty years to 2050. Six key development regions will form the foundation of the plan including; the northern region, which includes the construction of a university town and the northern adjustment region; the central region, which includes the construction of Guangzhou New City, and Shiqiao City adjustment region; and the southern region, which includes the Nansha Economic and Technological Development Zone, development of a deep water harbour on Longxue Island, and the middle agricultural region. In this study, by use of scenario analysis, a hypothetical future will be determined based on predictive data of the future obtained from the Guangzhou Research Institute of Environmental Protection (GRIEP). Subsequently, the effectiveness of sustainable initiatives will be investigated by nesting countermeasures within the scenarios. Finally recommendations in the area of sustainable management of water resources that impact on the decision making process in terms of planning for future deductions in waste, and remediation of current pollution levels will be expressed.

Objectives

The objective of this research was to predict the future water quality of the Shawan River in the Panyu District, with relation to changes in the water quantity utilized to fuel industrial and domestic development up to the year 2050. This research could be applied to rapidly urbanizing and industrializing regions of developing countries.

Area of focus

The city of Guangzhou

The city of Guangzhou sits in the center of Guangdong Province, and is located at the confluence of the North River (Bei), East River (Dong), and the West River (Xi), which converge to form the Pearl River (Figure 1).

Guangzhou governs ten city districts and town county level towns. The total area of Guangzhou is 7,434.4 km^2, and the population is over 10 million people. The ten districts comprised within the city government's jurisdiction are Dongshan, Liwan, Yuexiu, Haizhu, Tianhe, Fangcun, Baiyun, Huangpu, Panyu, and Huadu. These ten districts encompass an area of 3,718.5 km^2 – 50% of the entire city area. The remaining 50% of the area is

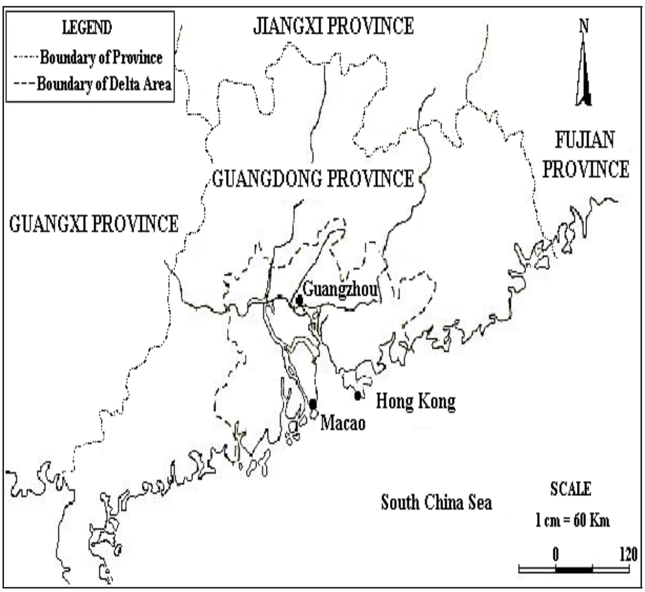

Figure 1 Guangdong Province – showing the extent of the Pearl River Delta Region (from Tao, 1999)

encompassed within the Conghua and Zengcheng City Districts, located northeast of Guangzhou City (Guangzhou Political Boundaries [Internet]).

Panyu district

The total land area of the Panyu District is 1,313.8 km^2, of which approximately 65% or 852.3 km^2 is land and 35% or 461.5 km^2 is made up of waterways and external water regions.

In the development of the Panyu District, six key development regions will be formed, with each district undertaking a predetermined function (Figure 2). These six development districts are as follow.

1. North adjustment district: at present this area is an important industrial base located just south of Guangzhou city, in the future this area will not be developed to levels higher than at present.
2. Shiqiao adjustment region: this region will also not undertake a high level of development in the future, but will form the centre for governmental administration, transportation, and goods exchange.
3. Guangzhou University Region: this region will be developed into the new base of education, research and hi-tech facilities.
4. Guangzhou New City Region: in this region Guangzhou New City will be constructed and will form a commercial, residential, and tourism centre.

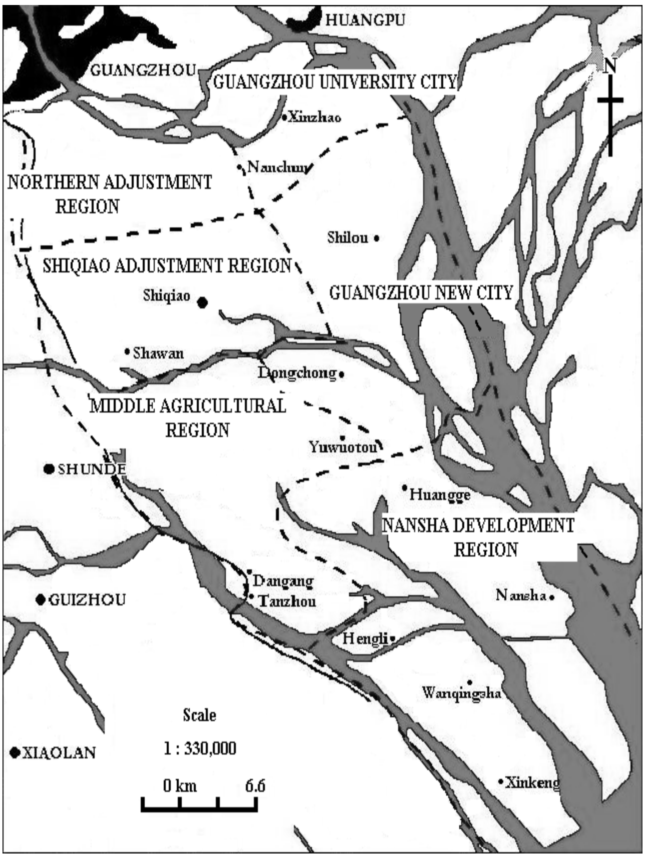

Figure 2 Distribution of development districts within Panyu district (source: USGS)

5. Nansha New Harbour Area: including the Nansha economic and technological development area, and the Pearl River Management area will form the centre for transportation, goods and service exchange, heavy industry, IT industries, and harbour industry, and will form an important link between Guangzhou and Hong Kong.
6. Agricultural Region: this region will be the focal point of agriculture in the Panyu District, and will also be used as an important processing area, and chemical production region.

Shawan river

The Shawan River is located in the center of the Panyu District and flows in roughly a west to easterly direction originating at the boundary between the Panyu and Shunde Districts, with the confluence of the Shunde River and the Chencun Rivers. Ultimately it discharges to the Shizhiyang River, which forms the last section of the main channel of the Pearl River (Figure 3). Being located within the Pearl River Delta the Shawan River is part of a large network of interconnected streams and waterways.

The total length of the Shawan River is 25.7 km, and it has an average width of 300–600 m, and average depth of 5–9 m. It is also subject to tidal interactions (ebb and flow) twice a day.

Information for base of calculations

Daily water consumption

The current per capita daily water consumption in the Panyu District as quoted by GRIEP is 370 L/cap-d (based on registered population). However, this value is expected to increase as development advances within the region, giving people more disposable income and the ability to increase water use for purposes other than household purposes. The value that has been predicted for the Panyu District in the future is 450 L/cap-d. This water consumption value is based on both the registered and migrant population.

Composition of typical sample of domestic sewage

The values of the pollutant concentrations used in the following calculations were taken from measurements of the composition of domestic sewage for New Wu Yang City in the Tianhe District of Guangzhou City. Table 1 shows these values. Note that the Chemical

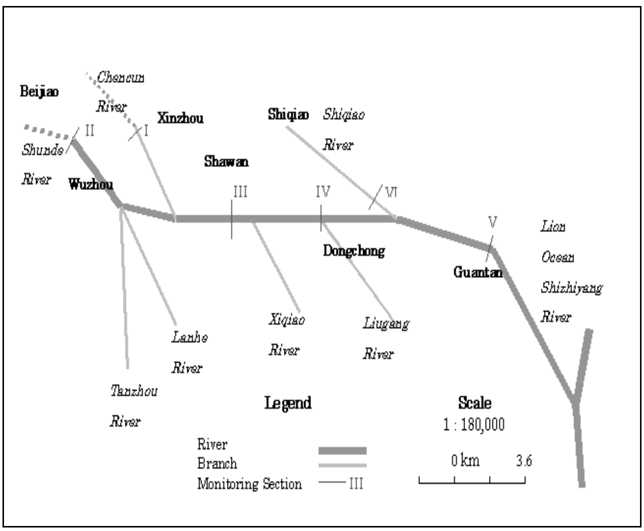

Figure 3 Simplified network of the Shawan river (source: GRIEP, 2001)

Table 1 Chinese environmental surface water standards

	Class I	Class II	Class III	Class IV	Class V
PH	6.5–8.5	6.5–8.5	6.5–8.5	6.5–8.5	6–9
COD_{Cr} (mg/L)	< 15	< 15	15	20	25
COD_{Mn} (mg/L)	< 2	4	6	8	10
BOD_5 (mg/L)	< 3	3	4	6	10
DO (% saturation)	90%	60	50	30	20
Ammonium nitrogen (mg/L)	0.5	0.5	0.5	1.0	1.5
Oil (mg/L)	0.05	0.05	0.05	0.5	1.0
Fecal coliforms (colony forming units/ml)	200	1,000	2,000	5,000	10,000
Use characteristic	National natural protection area	Domestic water resource (Level 1 protection area)	Domestic water resource (Level 2 protection area)	General industrial water use	Agricultural water use

Oxygen Demand (COD) is measured using the manganese method (also the preferred method of measurement in Japan) rather than the typical chromate method that is used in most other countries of the world.

Future predicted flowrate

Calculations to predict the remaining water within the river were based on a mass balance of flowrate, and in calculations performed by the Guangzhou City Government the flowrate defined by the 90% probability of the lowest month was used in all predictions (37.2 m^3/s for the Shawan River). In future predictions of water supply to the Panyu District it has been estimated that the Shawan River will supply 50.2% of water. Two other flowrates were used in this study, the upper and lower values defining the range for the dry season November to February (low water season) 307 and 432 m^3/s.

Future predicted water quality

Definition of the scenarios implemented

Two base scenarios were implemented for the two future years of 2020 and 2050. The two scenarios used were defined as follows.

1. Worst-case scenario – no wastewater treatment is done before discharging into the river. Not knowing accurately what industrial activity is likely to be located in the Shiqiao Adjustment Region and Guangzhou New City Region, it was assumed that no industrial wastewater would be returned to the river, therefore, the pollution load would be predominantly from domestic wastewater.
2. Best-case scenario – wastewater treatment including a high degree of tertiary treatment is used to remove 90% of the pollution load. As in scenario 1 the effect of industrial wastewater was not included.

Although at present there are no wastewater treatment plants in operation in the Panyu District, there are plans for the construction of such facilities in the near future. Therefore, it is expected that the actual future case will be somewhere between scenarios 1 and 2.

Calculation protocol to predict future water quality

The main assumptions that were made in the following calculations were:

- no self-purification in the river (background pollutant concentrations remain constant with time);

- the concentration of pollutants discharged was evenly distributed over the cross-sectional area of the river;
- no effect due to tidal action on concentrations;
- the river was completely mixed;
- common intake and return point for water taken from the river;
- the pollutant concentrations remained constant over time; and
- the current flowrates would remain constant over time.

The current and future pollution loads for the three pollutants investigated (BOD, COD_{Mn}, and NH_4-N) were based on 370 L/cap-d in the year 2000, and 450 L/cap-d in the years 2020 and 2050.

Only the populations of the Shiqiao Adjustment Region and Guangzhou New City Region were included in the calculation of water returned from domestic activities, as these two regions assert the greatest influence on the Shawan River. The predicted population for the Panyu District in 2050 is 4.15 million of which 2.2 million will be in the above two regions. Similarly, the predicted population in 2020 is 3.4 million, so through a process of linear interpolation the projected population in these two regions was estimated at 1.8 million. The total daily mass of pollutant (ton/d) was used within this research and was obtained by multiplying the pollution load by the population.

Finally, the computed total daily mass of pollutant was divided by the future predicted flowrate to obtain values of the pollutant concentration within Shawan River, the final pollutant concentration given in the units of mg/L.

Taking into account background concentration of pollutants

The background concentration of the pollutants in the river was taken to be the average of the monitored water quality values as measured by GRIEP. Subsequently, the final concentration of the pollutant in the river including the background concentration was calculated through a mass balance equating the initial concentration (background) in the natural flowrate before water was removed for human activities with the flowrate after human activities before inclusion of return water. Table 1 shows the National Surface Water Quality Standards for China.

Results of simulation of scenarios 1 and 2

Results of predicted water quality for scenarios 1 and 2 for the 90% probability of the lowest month of flow are shown in Table 2. Although there is sufficient water to meet water demand in the district, only approximately one third of the natural flow remains.

As would be expected the future water quality is highly dependent on the volume of water remaining within the river. Therefore, when the 90% probability of the lowest flow month is used, in both scenarios the future water quality predicted greatly exceeded Class V of the National Surface Environmental Quality Standards. When the range of flowrates typical during the low flow season were investigated, the resulting predictions in water quality were reasonable given the degree of error inherent in this mathematical approach used.

Table 2 Predicted future water quality for both Scenarios 1 and 2 for Flowrate of 37.2 m^3/s (unit: mg/L)

Year of prediction	Scenario 1		Scenario 2	
	2020	2050	2020	2050
BOD	170.12	207.40	18.03	21.76
COD_{Mn}	97.33	118.18	12.27	14.35
NH_4-N	16.93	20.83	1.85	2.22

For both the 307 and 432 m^3/s flowrates in 2020 and 2050, under both scenarios 1 and 2, the predicted water quality would equate to Class I for both NH_4-N and BOD and Class II for COD_{Mn}. Under both scenarios the predicted water quality was most influenced by the background concentration.

Effect of countermeasures

Two countermeasures were employed and subsequently three analyses were conducted for the two scenarios above by assuming that sustainable initiatives are undertaken to reduce the level of water demand and consumption.

1. Countermeasure One (Industrial saving) – in this analysis it was assumed that sustainable measures were implemented in the industrial sector to reduce the amount of water consumed by 50% of the current projected amount.
2. Countermeasure Two (Domestic saving) – in this analysis it was assumed that sustainable measures were implemented within the domestic sector to reduce the domestic per capita consumption from 450 L/cap-d down to 400 L/cap-d.
3. Countermeasure Three (Industrial and domestic saving) – this analysis was a combination of the above two analyses.

There was very little effect of the industrial demand and domestic consumption under both scenarios 1 and 2 for the higher flowrates (307 and 432 m^3/s). The resulting predictions in the water quality were the same as running the basic scenarios without changes to the water removed for human activities, which would imply that countermeasures are not required for the higher flowrates. The predicted water quality for the higher flowrates is much more dependent on the background concentration. Therefore, reductions in resulting water quality of the river would be more likely attained by trying to reduce the background concentration rather than through the use of countermeasures.

Comparison of the predicted water quality between implementation of the two main countermeasures for each scenario versus base scenarios for the year 2050 is shown in Table 3. Although predicted water quality far exceeded Class V of the Standards in all three analyses, the greatest change was obtained from reduction in the industrial water demand, equating to 63% reduction over base scenarios. Furthermore, with inclusion of wastewater treatment, predicted water quality can attain water quality standards.

Main findings and recommendations

- It was found that greatest change was observed when flowrates were low. The lower the flowrate the higher the likely impacts on water quality. In some cases reductions of two-thirds of the flowrate was observed.
- The countermeasure – sustainable initiative – that showed the greatest improvement in water quality within this analysis was a reduction in the industrial water demand.

It is recommended care be taken to safeguard the flowrate of the river, as the most noticeable changes occurred when the flowrate was low. In order to avoid this situation industrial countermeasures appeared to impart the greatest influence. This could be

Table 3 Comparison of countermeasures versus base scenarios for 90% probability of lowest flow (unit: mg/L)

2050	Base cases		Countermeasure 1		Countermeasure 2	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2	Scenario 1	Scenario 2
BOD	207.4	21.8	62.3	7.3	184.2	19.4
COD_{Mn}	118.2	14.4	37.0	6.2	105.2	13.1
NH_4-N	20.8	2.2	6.2	0.8	18.3	2.0

achieved through the implementation of water saving, water recycling, the use of brackish water for cooling, and the implementation of economic pricing initiatives. The further promotion of inter-district governmental policy initiatives could also be employed to prevent upstream pollution from influencing downstream proposals, further enhancing sustainable water management of the Shawan River.

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