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Water quality management of heavily contaminated urban rivers using water quality analysis simulation program

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ABSTRACT

Precisely management of water quality in urban rivers is of significant where water environmental capacity provides a useful tool. This study presented a water quality analysis simulation program model-based approach for dynamical load reduction in Ashi River, highly contaminated tributaries of Songhua River, China. The actual and surplus dynamic environmental capacity of COD_{Cr} and NH_3-N, as the two controlling endpoints, were computed based on "segment-end-control" method for monthly or seasonal management. The dynamic pollution control scheme and monthly to annual control strategies were produced based on calculated results. Results show that COD_{Cr} and NH_3-N need to be cut down to approximately 462.47t/a and 5.2t/a at Zhujia-Acheng down reach and 282.42 t/a and 9.25t/a Acheng down-Chenggaozi town reach, respectively under 90% hydrological design reliability to keep the water quality at class-IV. The COD_{Cr} and NH_3-N of three ditches should be strictly controlled throughout the year. Some interesting temporal-spatial characteristics of surplus environmental capacity were also found in the study. This study provides local governments with technical measurements and policy recommendations for highly contaminated water body treatment. In the future, the river water quality management in the winter season should take into particular consideration.

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INTRODUCTION

River contamination release management is of critical for surface water conservation in all the countries. Typically, United States established National Pollutant Discharge Elimination System according to Clean Water Act and proposed Total Maximum Daily Load (TMDL) plan (Chapra 2003; Elshorbagy *et al.*, 2005; Grismer, 2013) to make sure the water quality meeting the standards. In China, a Chinese version of the TMDL plan has been executed for a dozen of years since Chinese State Council approved “The Total Discharge of Major Pollutants Control Plan During the Period of Eleventh Five-Year-Plan” in 2006 (The State Council, 2006). Pollutant load reduction, mainly on COD_{Cr} and NH_3-N, in major Chinese watersheds has achieved preliminary goals, and water quality has been gradually improving (MEP-PRC, 2014). However, urban heavily contaminated water body is still a big challenge. Total amount control of pollutant loading can be designed by an administrative goal-oriented approach and an environmental capacity-based approach (Meng *et al.*, 2007; Meng *et al.*, 2008; Wei *et al.*, 2014). The former approach was dominant during the past “Eleventh Five-year Guideline” and “Twelfth Five-year Guideline”, i.e., 2006-2015. Although the administrative goal-oriented approach has played an important role in overall pollutant discharges control and environmental quality recovery, some practical issues were exposed while using this approach. For example, in heavily polluted water bodies, discharge reduction targets were met, while water quality recovery was not obviously successful; in contrast, discharge reduction tasks were still evenly allocated even in some regions with good environmental quality, which restricted the regional economy development to some extent (Wei *et al.*, 2014). These problems can’t be avoided as long as decision makers apply an administrative goal-oriented approach. To this end, the management of total amount control of pollutant discharge in China is moving from an administrative goal-oriented to an environmental capacity-based pattern. In April 2015, the Chinese State Council executive meeting deliberated and issued the “Action Plan for Prevention and Control of Water Pollution” (hereinafter referred to as the “Ten Regulations for Water”), which is a milestone event in Chinese water pollution control. The regulation proposed “strengthening the management of environmental quality objectives, deepen the total amount control of pollutant discharge” as executive orders (The State Council, 2015). To implement this updates, China EPA issued a precisely management system named as “Three Baselines One List” in 2018, which covered the water environment management. Water environmental capacity (WEC), i.e., assimilative capacity of water bodies (Hashemi *et al.*, 2017), is an important basis for water quality management. In recent years, scholars conducted extensive studies on the WEC-based surface water management by examining the estimation technique, load allocation, and economic evaluation (Liang *et al.*, 2015; Mahjouri and Bizhani-Manzar, 2013; Huang *et al.*, 2009; Brouwer *et al.*, 2008). WEC calculation generally includes river hydrology, hydraulic facilities, natural geographical conditions, the way of pollutant discharge and other characteristics. The commonly used deterministic methods include the analytical formula method, trial-and-error method and systemic optimization analysis method (Abbas *et al.*, 2018; Chen *et al.*, 2014; Dong *et al.*, 2014). The analytical method, which is the simplest and most suitable for steady-state reaches or rough calculation, has been widely used before and has played an important role in the past. With the accumulation of water environment observations year by year, more sophisticated water quality modeling software (i.e., Qual2K, WASP) are becoming more and more popular in the practical discharge planning (Zhang *et al.*, 2012; Shi *et al.*, 2010). These programs can calculate dynamic changes in WEC under the different conditions of water hydrology and period and reflect the practical assimilative capacity. The trial-and-error method has practical feasibility based on water quality modeling software. If social and economic factors are considered as constraints, the systemic optimization method will be recommended. Recently, the seasonal and dynamic management of surface water quality has been a focus (Chen *et al.*, 2016; Zhao *et al.*, 2014), due to the trends of more sophisticated management. This investigation is mainly a case study of load reduction for a highly contaminated river, during the period of “total load control pattern updating” in China based on a dynamic water environmental capacity approach. The study area is the water pollution control plan of the Ashi River, a large tributary of the Songhua River. It inputs a large amount pollutants into the Songhua River, especially in the downstream area located in Harbin City, which has a population of nearly 10 million. The assimilative capacity of the objective water body is calculated by a trial-and-error method with the widely used WASP model. Water quality analysis simulation program (WASP) has been widely applied around the world. It has particular advantages on receiving water modeling and in-stream water quality process (Shi *et al.*, 2010; Elshorbagy *et al.*, 2005). COD_{cr} and NH_3-N were chosen as end points according to local government policy. Monthly to annual load reduction strategy at each outlets were proposed according to the function zoning and actual WEC values.

MATERIALS AND METHODS

The study area

Ashi River Basin is the cultural candle of the Jin Dynasty in ancient China (1115-1234). As the largest tributary on the right side of the Songhua River, the Ashi River has an actual length of 257 km and a straight length of 133 km of main stream and can be divided into the upstream Acheng District Section (Zhujia-Chenggaozi) in the Acheng district and the downstream Harbin City Section (Chenggaozi-Songhua River) in Harbin city (Fig. 1). This work focuses on the Acheng District Section, due to the large amount of scattered point sources along this river reach. There are several tributaries in this region, such as the Nanda, Chengnan, Haigou and Miaotaizi ditches. These tributaries pass through towns and villages, receiving domestic and industrial wastewater. The distribution of outfalls is shown in Figs. 1 and 2. The Yuquan ditch mainly receives domestic sewage from the Yuquan region. The Nanda and Chengnan ditches mainly receive industrial wastewater from some small plants and agricultural nonpoint wastewater from the Shuangfeng area and the Acheng area. The Haigou and Miaotaizi ditches are seasonal streams flowing through the village and receive domestic wastewater. Each sewage outfall is

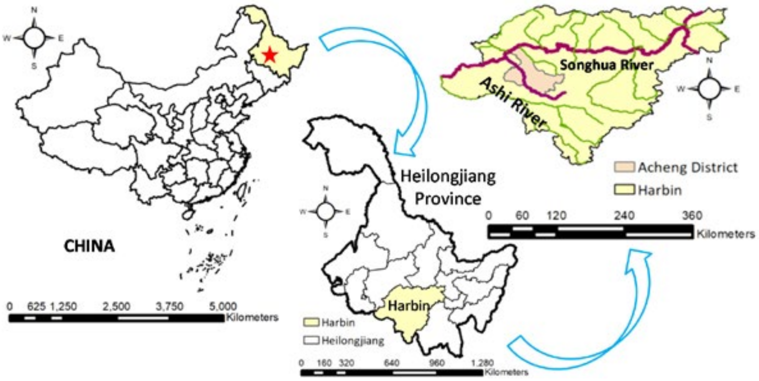


Fig. 1: Geographic location of the study area in Ashi River and Acheng District

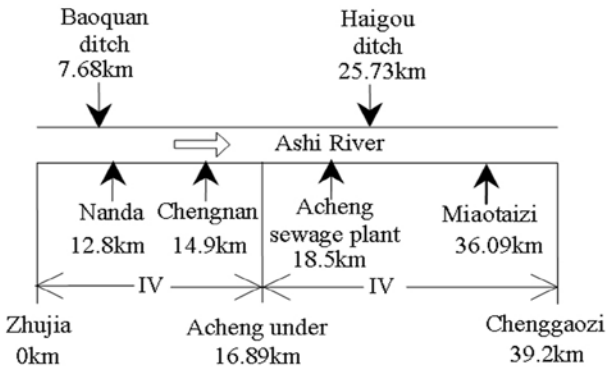


Fig. 2: Discharging system of the study area (Zhujia-Chenggaozi River Reach)

characterized by monthly monitoring concentration (mg/L) and discharge (m^3/s). The Acheng reach of the Ashi River is divided into two control units namely Zhujia-Acheng down and Acheng down-Chenggaozi town as shown in Fig. 2. The Acheng Waste Water Treatment Plant (WWTP) is planned and designed according to the disposal capacity of 100,000 tons per day (in two phases, 50,000 tons per day in one phase and 50,000 tons per day in the second phase). The effluent meets the discharge standard and meets the 1A standard of 'Pollutant Discharge Standard for Urban Sewage Treatment Plant' (GB18918-2002). The total area of Ashi River basin is 3,493 km^2. Ashi River Basin's mountainous area is 1856 km^2, which accounts for 53.1% of the total drainage area. The river terrain has hills and plains, and the hilly area is 539.2 km^2, which accounts for 15% of the total drainage area; the plain area is 1185.8 km^2, accounting for 33.9% of the total basin area. It has many tributaries, including 79 large and small tributaries in the watershed, with a total length of 1277.86 km. The Acheng River and the Haigouhe River are the longest tributaries (Sui 2013). It has mountainous runoff that mainly depends on precipitation. It receives 70% to 80% of annual precipitation from July to September. The average flow of Ashi River is 7.5 m^3/s in spring; 14.5 m^3/s in summer and 2.5 m^3/s in winter. The Ashi River begins to freeze in mid-November every year, and thawing starts in April of the following year. Climatic winter lasts for up to five months. The average summer discharge was 7.2 m^3/s in the last decade.

Water function zoning (WFZ) and water quality monitoring

According to "Provincial Standard for Surface Water Function Zones in Heilongjiang" (DB23/T740-2003), the whole water environment function zoning and objectives in the Ashi River are shown in Table 1.The study area, Zhujia-Chenggaozi Section, is set as agriculture dominant and needs to meet the requirements of Grade IV national water quality standards. Five years (2009–2013) of monthly monitoring data, including one sewage outlet, three monitoring stations and five tributaries (Fig. 2), were collected by the Environmental Monitoring Center of Harbin City. Water samples were not collected in March, April, November and December due to ice cover and safety problem. Five parameters including NH_3-N, COD, COD_{Mn}, DO and BOD_5 were considered in the study. However, COD and NH_3-N were only focused since they were the only controlling end points of Chinese Government.

The monitoring results and the government report (EPA-HP, 2014; EPA- HC, 2014) indicate that the water quality of Ashi River decreased from upstream to downstream. The Zhujia-Acheng section met the Grade III criteria, while the Acheng-Chenggaozi section was below the Grade IV criteria.

The Ashi River Pollution Control Project

In recent decades, the 'golden' river has received a large amount of industrial wastewater and sewage with the rapid development of local economy. The river ecosystem has been completely damaged, seriously threatening the water quality of Songhua River (Wang *et al.*, 2013; Sui 2013). In 2012, the Harbin city government started the Ashi River comprehensive pollution control project (Zhou *et al.*, 2011). The study areas in this project was located in the downstream section with a total length of 22 km from the Ashi River confluence into the Songhua River to the Mingqiang Village, mainly located in Daowai District and Xiangfang District of Harbin city. The Ashi River project area covered five

Table 1: Basic information of Ashi River WFZ and water quality objectives

First level of WFZ	Second level of WFZ	River Reach		Length (km)	Water quality target	Upstream water quality
		Start section	End section			
Reservations Area		Xiquanyan reservoir	Zhujia	39.2	III	II
Acheng exploitation Area	Acheng agricultural-oriented area	*Zhujia*	*Chenggaozi*	*55.8*	IV	III
	Harbin discharges control area	Chenggaozi	Huanjiawaizi	20.4	IV	IV
	Harbin buffering area	Huangjiawaizi	Ashi River estuary	17.6	IV	IV

tributaries, one of which was Xinyi Ditch that also belongs to the Target Rivers of "Three Ditches One River" water quality recovering project of Harbin City. From the Environment Quality Bulletins of China, Heilongjiang province and Harbin city, it can be seen that water quality of the main stream of Songhua River has improved in general, but it is still arduous to meet the goal of water environment recovering and conservation in associated tributaries. There has not been significant water quality improvement in a highly contaminated city river like Ashi River after the total amount control action suggesting more discharge reductions be necessary.

Load reduction based on dynamic water environmental capacity (WEC)

Dynamic WEC provides an advanced technology to manage the watershed pollution discharge on a seasonal or monthly basis. It makes good use of water resources relative to WFZ and realizes the pollution control and sustainable economic development. A flow chart for the river basin pollution control and load reduction based on dynamic WEC is shown in Fig. 3. We defined actual WEC and ideal WEC here. The actual WEC considers initial cross-section water quality and tributary pollutant load, while ideal WEC only considers the stretch of control unit and presumes no upstream or bankside pollutant enters, i.e. intrinsic or baseline assimilative capability of the water body. The actual WEC can also be calculated directly by sophisticated water quality models without calculating ideal WEC in advance. In this study, WEC was defined under 90% hydrological design reliability as usual, and it set the control cross-sections at each control unit as Grade IV national criteria of surface water quality.

A river function zone is usually divided into independent Control Units to calculate the WEC individually. Routine administrative monitoring cross-sections are used to be selected as control cross-section. For the stretch of river in one dimension, places of pollution outlets and tributary confluence are chosen as the control cross-section. The WEC of control units can be calculated by different approaches, such as segment-head-control, segment-end-control, or function zone-end-control which are suitable for the drinking water source area, the developing area with a lower requirement on water quality, and the heavily polluted area, respectively. In this study, the segment-end-control method was selected, assisted by the WASP model. The WEC of each segment in the given control

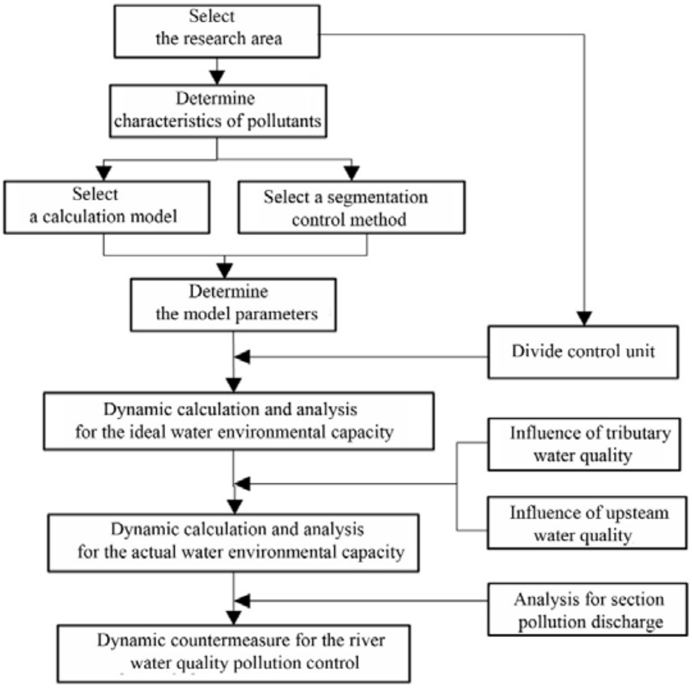


Fig. 3: Flowchart of load reduction planning at environmental function zones based on dynamic water environmental capacity

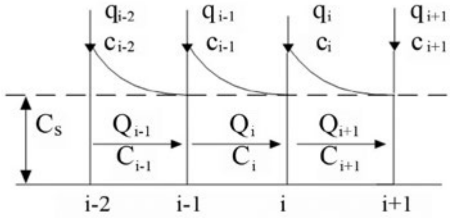


Fig. 4: Schematic diagram of segment-end-control approach for environmental capacity estimation

unit was calculated from downstream to upstream by a segment-end-control method (Fig. 4).Therefore, in the each segment of control unit, the water quality objective in the downstream cross-section was set to Grade IV; the maximum load was then calculated from the pollutant outlets or tributaries to meet this requirement. This maximum load can be defined as WEC of that particular segment. The summation of the WEC of these segments is the WEC of the given control unit. It can be noted that negative values of WEC can also be present. The WEC at the section head and the *i*th cross-section can be calculated by Eqs. 1 and 2, respectively.

$$\mathrm{E}_0 = Q_0(C_s - C_0) \tag{1}$$

$$E_i = \frac{C_s(Q_i + q_i)}{f(x_{i+1} - x_i)} - Q_i C_s \tag{2}$$

Where, *E* is environmental capability; *Q* is the mainstream discharge; *q* is the tributary discharge, C_0 is the initial concentration of the control unit head cross-section; C_s is the objective concentration; $f(x_{i+1}\text{-}x_i)$ is a dimensionless index to denote the advection-diffusion-reaction process and capability within the ith segment/cross-section. The value of the pollutant concentration at the end-cross section when head cross-section concentration is maintained at the unit concentration, e.g., 1 mg/l. In the simplest case, by considering the one dimensional steady state and ignoring longitudinal diffusion, it can be estimated by Eq. 3.

$$f(x_{i+1} - x_i) = \exp(-\frac{kx}{u}) \tag{3}$$

WASP model for WEC calculation

WASP is a dynamic compartment model that can be used to analyze a variety of water quality problems in diverse water bodies such as ponds, streams, lakes, reservoirs and rivers. The equations solved by WASP are based on the key principle of the conservation of mass, and the model can describe the temporal and spatial variation of water quality indexes (Wool *et al*., 2001), see Eq. 4. Considering the one-dimensional river network, it can be represented by a one-dimensional equation. Assuming vertical and lateral homogeneity, we can obtain the one-dimensional transport equation for water quality as Eq. 5 (Wool *et al*., 2001). During the calibration, average relative error at different site is used for evaluation.

$$\begin{aligned}\frac{\partial C}{\partial t} = &-\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}\left(E_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(E_y \frac{\partial C}{\partial y}\right) \\ &+ \frac{\partial}{\partial z}\left(E_z \frac{\partial C}{\partial z}\right) + S_L + S_B + S_K\end{aligned} \tag{4}$$

Where;

C is concentration of the water quality constituent, mg/L or g/m3;

t is time, day;

U_x, U_y U_z are longitudinal, lateral and vertical advective velocities, m/day;

E_x, E_y, E_z are longitudinal, lateral and vertical diffusion coefficients, m^2/day;

S_L is direct and diffuse loading rate, g/m^3/day;

S_B is boundary loading rate (including upstream, downstream, benthic, and atmospheric), g/(m3·day);

S_K is total kinetic transformation rate; positive is source, negative is sink, g/(m^3·day);

$$\frac{\partial}{\partial t}(AC) = \frac{\partial}{\partial x}\left(-U_x AC + E_x A\frac{\partial C}{\partial x} + E_x A\frac{\partial C}{\partial x}\right) + A(S_L + S_B) + AS_K \tag{5}$$

RESULTS AND DISCUSSION

Generalization of river reach

Considering the monitoring sections settled by Harbin EPA, tributaries, river confluence, administrative divisions and the actual situation, the Acheng District Section was divided into three segments, different from water quality control units (Fig. 5). The reach hydrologic and hydraulic characteristics are also shown in Table 2. Among those three segments, the largest load of COD is from the Acheng Up-Acheng Down segment with a total amount of 13 542.11 t/a discharge, where the industrial source is 340 t/a, the domestic discharge in the city is 11861.8 t/a, and the remaining is domestic discharge from villages (Sui 2013).

WASP model calibration and verification

The WASP model for the Acheng segment was calibrated according to discharge data from the Acheng hydrological station and water quality monitoring data from the Acheng district in 2008-2011 and verified by 2012 data. The CBOD process was used to simulate COD transport and degradation in Sui (2013). Based on experiences and relevant literature, parameters of the model are specified within the parameters' own range because the model has a relatively large number of parameters, and the model does not automatically optimize by itself. The accuracy of water environmental capacity is closely related to the accurate pollution degradation coefficients, which is temperature-dependent (Li and Ma 2012). We set K_{COD}=0.072d^{-1} and K_{NH3-N}=0.035 d^{-1} in the frozen and transition period and K_{COD}=0.12/d and K_{NH3-N}=0.085/d in the non-frozen and transition period. Minimum flow is used as the design flow for the corresponding month. Hydrological data in 2012 is shown in Table 3. We used a coarse adjustment and minute adjustment method in the calibration process. The calibration shows that water temperature, discharge, COD, NH_3-N attenuation coefficient, and sediment oxygen demand (SOD) are sensitive.

Figs. 6 and 7 show the COD_{Cr} and NH_3-N verification results at the Chenggaozi cross-section; with the average relative error 2.73% and 1.67% respectively. The final parameters of the model are listed in Table 4.

Available WEC in control units

COD_{Cr} and NH_3-N, which are the two major pollutant indicators in the National "Twelfth Five-Year Guideline", were taken into consideration at the Acheng District Section of the Ashi River. According to WFZ, the water quality in the Acheng District Section needs to be at grade IV of surface water national standards GB3838-2002. It can be set as COD_{Cr}=30 mg/L and NH_3-N =0.15 mg/L. Two control units (CUs) were set up, "Zhujia-Acheng down" CU1 and "Acheng down-Chenggaozi" CU2 according to the government administrative practices (Fig. 2). There are four tributaries within the study area, including the Nanda ditch, Chengnan ditch, Haigou River and Miaotaizi ditch. They greatly influence the Ashi River main stream due to their high pollutant concentrations. For CU1, the upstream doesn't meet the water quality standards and needs to be taken into consideration when calculating WEC. The two control units are divided into 6 segments for WEC calculation. Table 5 shows the equivalence relationship of WEC at the cross-section and the segment. For convenience,

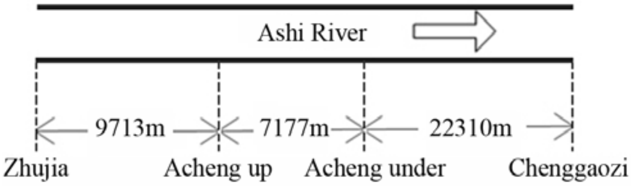


Fig. 5: Schematic diagram of Acheng District Section of Ashi River

Table 2: Segments and hydrographic information of Acheng District Section for WASP model

Segment name	Length（km）	Width (m)	Depth (m)	Slope (m/m)	Roughness coefficient
Zhujia-Acheng Upper	18.789	30	0.4	1/1500	0.05
Acheng Upper - Acheng Down	7.177	141	0.8	1/2000	0.035
Down Acheng-Chenggaozi	30.565	43	0.5	1/2500	0.025

Table 3: Hydrologic parameters of Acheng District Section in Ashe River

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Discharge(m^3/s)	2.35	2.32	2.52	2.50	2.18	9.08	11.96	8.19	4.41	5.00	2.63	2.27
Average velocity(m/s)	0.35	0.30	0.38	0.45	0.84	1.19	1.39	1.59	1.57	0.79	0.52	0.32

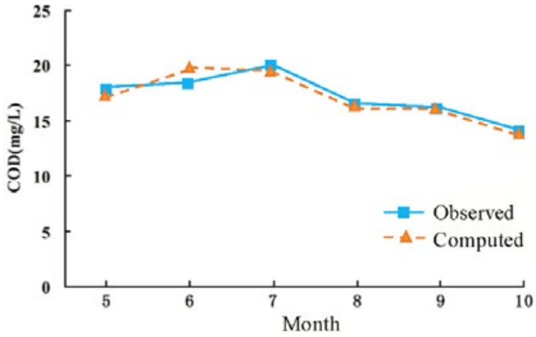


Fig. 6: Verification of COD_{Cr} in Chenggaozi cross-section (2012)

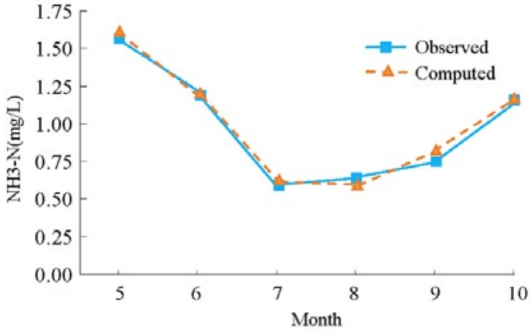
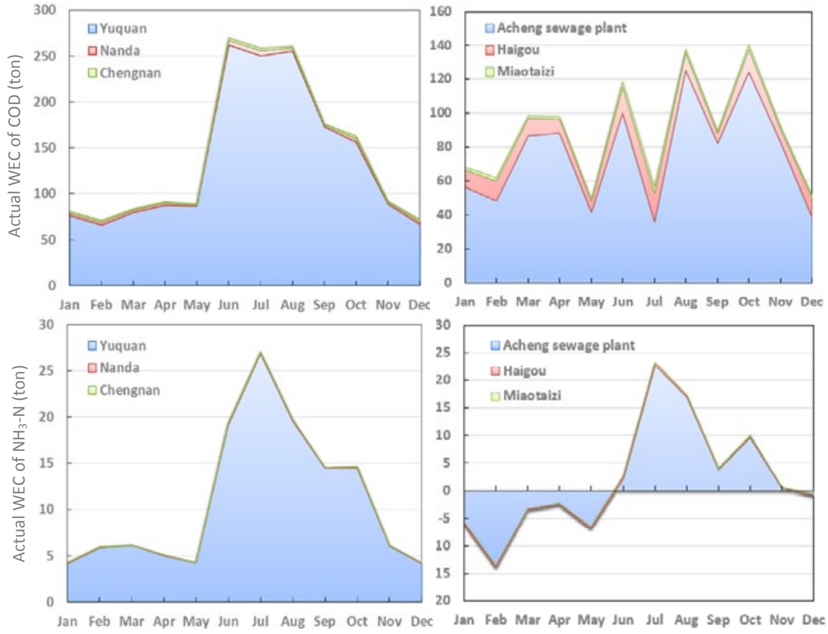


Fig. 7: Verification of NH_3-N in Chenggaozi cross-section (2012)



Control Unit 1

Control Unit 2

Fig. 8: Actual dynamic water environmental capacity of COD and NH_3-N at each outlets and control units

WEC defined by downstream cross-section (the 2nd column in Table 5) was mainly used in this study. Fig. 8 presents dynamic WEC of COD and NH_3-N at each outlet and control unit. Obviously, CU1 and CU2 have different patterns of monthly WEC both for COD_{Cr} and NH_3-N.In CU1, the WEC of COD_{Cr} and NH_3-N are both evidently large from Jun to Aug, mainly due to the high-flow in the summer. In CU1, the WEC of COD_{Cr} doesn't show such a pattern. The WEC of COD_{Cr} interestingly fluctuates (right upper plot at Fig. 8), probably due to the river flow and water quality fluctuation at the Acheng down cross-section and the head cross-section of CU2. Additionally, the WEC of NH_3-N gave negative values from Dec to May. This phenomenon might be explained by the water usage and domestic wastewater discharge at Acheng city as well as the ice layer and slow decomposition rate. The results also show that in CU1, the first segment (#1 in Table 5) has the dramatically dominant WEC not only for COD_{Cr} but also for NH_3-N, although it is only approximately 50% of the length of CU1.The same phenomenon was observed in CU2 as well.

Table 4: WASP model parameters for Ashi River (Li *et al.*, 2016)

Parameters	Symbol	Value	Unit
SOD (sediment oxygen demand)	SOD	0.2	g/(m^2·d)
SOD Temperature correction Factor	Θ_S	1.08	
Denitrification rate constant @20 °C	k_{12}	0.07	1/d
Denitrification temperature coefficient	Θ_{12}	1.07	
Oxygen to carbon ratio	a_{oc}	32/12	mgO$_2$/mgC
Phytoplankton death rate constant	K_{1D}	0.005	1/d
Half saturation constant for oxygen limitation	K_{COD}	0.35	mg/L
Phytoplankton maximum growth rate constant @20 °C	G_{p1}	1	1/d
Phytoplankton growth temperature coefficient	Θ_{p1}	1.07	
Phytoplankton respiration rate constant @20 °C	K_{1R}	0.12	1/d
Phytoplankton respiration temperature coefficient	Θ_{1R}	1.045	
Half saturation constant for oxygen limitation	K_{NIT}	0.5	mg/L
Deoxygenation rate constant @20 °C for COD	K_d	0.05	1/d
Temperature correction coefficient	Θ_d	1.05	
Fraction dissolved COD	f_{D5}	0.5	
Denitrification rate constant @20℃	K_{2D}	0.2	1/d
Denitrification temperature coefficient	Θ_{2D}	1.08	
Reaeration rate @20℃	k_2	0.5	(1/d)
Reaeration temperature coefficient	Θ_2	1.03	

Table 5: The equivalence relationship of WEC at the cross-section and the segment

No.	WEC of the cross-section	WEC of the segment
#1	Yuquan	*Zhujia* cross-section (CU1 head) to the front of *Nanda* tributary mouth
#2	Nanda	The front of *Nanda* tributary mouth to the front of *Chengnan* tributary mouth
#3	Chengnan	The front of *Chengnan* tributary mouth to *Acheng down* cross-section (CU1 end)
#4	Acheng sewage plant	*Acheng down* cross-section (CU2 head) to The front of *Haigou* tributary mouth
#5	Haigou	The front of *Haigou* tributary mouth to the front of *Miaotaizi* tributary mouth
#6	Miaotaizi	The front of *Miaotaizi* tributary mouth to *Chenggaozi* cross-section (CU2 end)

The annual pattern of WEC is shown in Fig. 9. The values of the WEC of COD$_{Cr}$ and NH$_3$-N are 1707.16t/a and 131.57t/a, respectively in the reach of Zhujia-Acheng down for the year 2012. The environmental capacity of COD$_{Cr}$ and NH$_3$-N are 1061.75t/a and 26.07t/a, respectively in the reach between Acheng down and Chenggaozi town. It is quite evident from the analysis that the actual dynamic water environmental capacity of the above mentioned control unit is relatively large owing to upstream runoff, flow and contaminant degradation coefficient. Declination is observed in the pollutant assimilation capability of the water body, owing to decreasing water flow. Water pollution management is crucial for water environmental planning requirements throughout the year, especially in the months of

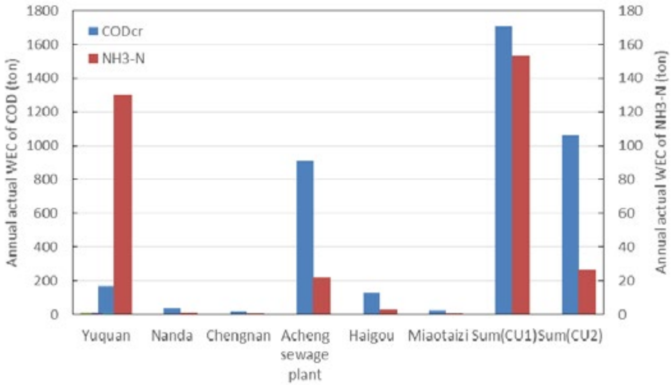


Fig. 9: Annual actual water environment capacity of COD_{cr} and NH_3-N at each outlets and control units

Table 6: Surplus water environmental capacity of COD_{Cr} at each outlet and control unit (ton)

Month	Control unit 1				Control unit 2			
	Yuquan	Nanda	Chengnan	Sum	Acheng sewage plant	Haigou	Miaotaizi	Sum
Jan.	46.39	-32.15	-7.01	7.23	-10.80	1.66	-23.80	-32.94
Feb.	36.12	-31.74	-6.79	-2.41	-17.13	2.85	-23.53	-37.81
Mar.	49.46	-32.18	-7.03	10.25	13.44	1.55	-23.82	-8.83
Apr.	57.69	-32.61	-7.27	17.81	14.30	0.31	-24.10	-9.49
May.	56.14	-33.13	-7.57	15.44	17.45	-1.20	-24.45	-8.20
Jun.	232.24	-29.90	-5.74	196.60	39.12	8.04	-22.31	24.85
Jul.	220.41	-29.28	-5.39	185.74	20.53	9.81	-21.90	8.44
Aug.	225.43	-31.50	-6.64	187.29	61.20	3.46	-23.36	41.30
Sep.	143.09	-33.00	-7.49	102.60	16.54	-0.84	-24.36	-8.66
Oct.	126.44	-30.73	-6.21	89.50	54.39	5.71	-22.86	37.24
Nov.	59.13	-32.81	-7.38	18.94	10.94	-0.27	-24.23	-13.56
Dec.	36.95	-31.99	-6.93	-1.97	-24.07	2.11	-23.70	-45.66
Year	1289.49	***-381.02***	***-81.45***	827.02	195.91	33.19	***-282.4***	-53.32

Note: Bold font denotes that the load reduction should be conducted in the given outlet or tributary.

lower discharge. Season-based control is necessary.

Pollution control based on surplus WEC

Subtracting current pollutant load at each outlet or tributary from actual WEC gives the surplus WEC. The pollutant load should be reduced by integrated pollution control in the area where the surplus WEC is negative. Watershed pollution prevention and control countermeasure in the Acheng District Section of the Ashi River is established, considering the pollutant discharge on the basis of dynamic WEC. In each pollution outfall, surplus WEC calculation results are tabulated in Table 6 and Table 7, and the total surplus WEC of each control unit are shown in Fig. 10.

In general, for COD_{Cr} assimilation, Zhujia-Acheng reach (CU1) has surplus environmental capacity in an annual scale, while the Acheng-Chenggaozi reach (CU2) has depleted the available WEC. Among those outlets and tributaries, Nanda, Chengnan and Miaotaizi ditch pollutant outfall were suggested to reduce the pollution sources in order to replenish the consumed WEC (Table 6). For NH_3-N assimilation, as for the COD_{Cr}, the reach of CU1 has enough surplus WEC while the reach of CU2 presents a slightly negative surplus WEC. The Nanda, Chengnan and Miaotaizi ditch pollutant outfall were also suggested to reduce NH_3-N output to the Ashi River (Table 7).Another option is to gather and treat the discharge from these ditches before they run into the Ashi River. In numbers, it is evident from Tables 6 and 7 that the COD_{Cr} and NH_3-N of Zhujia-Acheng down should be reduced by 462.47t/a, and 5.2t/a (Nanda and Chengnan), respectively, while the same contaminant for the reach between Acheng down-Chenggaozi town should be declined to 282.42t/a, and 9.25t/a, respectively. The COD_{Cr} environmental capacity of Yuquan pollutant outfall has a surplus every month, while the Nanda and Chengnan ditch

Table 7: Surplus water environmental capacity of NH_3-N at each outlet and control unit (ton)

Month	Control unit1				Control unit 2			
	Yuquan	Nanda	Chengnan	Sum	Acheng sewage plant	Haigou	Miaotaizi	Sum
Jan.	2.17	-0.09	-0.38	1.70	-6.06	-0.08	-0.79	-6.93
Feb.	3.88	-0.08	-0.38	3.42	-11.98	-0.05	-0.78	-12.81
Mar.	4.09	-0.09	-0.38	3.62	-4.25	-0.08	-0.79	-5.12
Apr.	2.99	-0.10	-0.39	2.50	-3.48	-0.10	-0.79	-4.37
May.	2.18	-0.09	-0.38	1.71	-6.58	-0.08	-0.79	-7.45
Jun.	17.12	0.00	-0.33	16.79	0.43	0.18	-0.73	-0.12
Jul.	24.81	0.02	-0.32	24.51	19.74	0.23	-0.72	19.25
Aug.	17.58	-0.05	-0.36	17.17	13.89	0.05	-0.76	13.18
Sep.	12.44	-0.09	-0.38	11.97	1.69	0.03	-0.79	0.93
Oct.	12.43	-0.02	-0.35	12.06	6.68	0.11	-0.74	6.05
Nov.	4.06	-0.1	-0.39	3.57	-1.29	-0.11	-0.79	-2.19
Dec.	2.15	-0.09	-0.38	1.68	-2.24	-0.07	-0.78	-3.09
Year	105.90	***-0.78***	***-4.42***	100.70	6.55	0.03	***-9.25***	-2.67

Note: Bold font denotes that the load reduction should be conducted in the given outlet or tributary

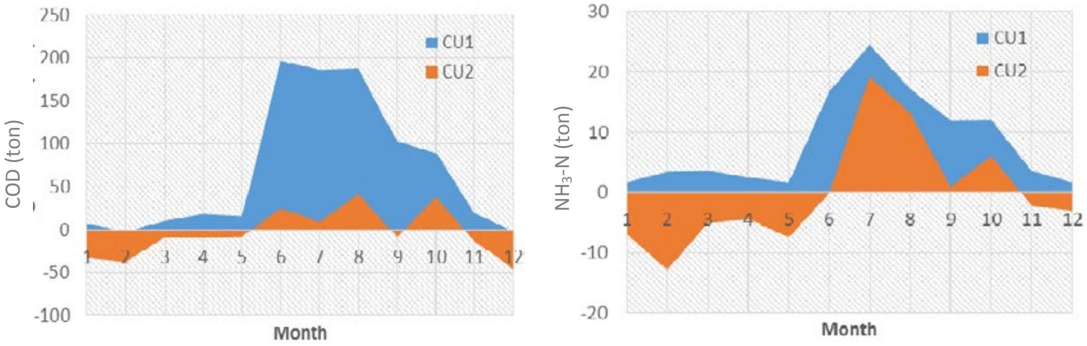


Fig. 10: Surplus dynamic water environmental capacity of COD and NH_3-N at Control Unit 1 and 2

pollution discharge of COD_{Cr} exceed the actual water environmental capacity. The affluent surplus WEC at the Yuquan cross-section, especially from Jun to Oct, mainly result from the good water quality upstream and because the dilution assimilation is strong. In temporal variation, surplus WEC in the Acheng wastewater treatment plant and Haigou ditch has negative values from January to May and from October to December. The Miaotaizi ditch is highly contaminated, due to NH_3-N throughout the year. It is suggested to decrease NH_3-N in this region by controlling coastal enterprises of Miaotaizi ditch and non-point source pollution. It is also interesting to find that COD_{Cr} WEC at the Acheng sewage plant became negative from Dec to Feb. It may account for the treatment effects of Acheng WWTP and degradation in the river turn to be lower during the extremely cold season at Harbin. A dynamic control scheme array was developed for each segment as shown in Table 8. Dynamic water environmental capacity can be improved by controlling the total pollutant load, which helps in the formulation of dynamic water environmental management and planning. At least a seasonal plan from the monthly result should be applied in practice. Of course, control of phosphorus-based pollutants will be the next step (Meng *et al.,* 2015). With the verified WASP model, future WEC can be easily predicted, and a future pollution control plan can be made from a monthly to annual scale in advance. It is a supplementary and move one step forward to the relative studies on Ashi River like Sui (2013); Wang *et al.* (2013).

Limitation and suggestions

In this study, the Harbin EPA only monitored water quality in ten months; November and December are heavily ice-covered and EPA suspend sampling.

Table 8: Dynamic control strategy of water pollution at Acheng District Section in Ashi River

Month	Yuquan	Nanda	Chengnan	Acheng sewage plant	Haigou	Miaotaizi
1	--	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N	NH_3-N	COD, NH_3-N
2	--	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N	NH_3-N	COD, NH_3-N
3	--	COD, NH_3-N	COD, NH_3-N	NH_3-N	NH_3-N	COD, NH_3-N
4	--	COD, NH_3-N	COD, NH_3-N	NH3-N	NH_3-N	COD, NH_3-N
5	--	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N
6	--	COD, NH_3-N	COD, NH_3-N	--	--	COD, NH_3-N
7	--	COD, NH_3-N	COD, NH_3-N	--	--	COD, NH_3-N
8	--	COD, NH_3-N	COD, NH_3-N	--	--	COD, NH_3-N
9	--	COD, NH_3-N	COD, NH_3-N	--	--	COD, NH_3-N
10	--	COD, NH_3-N	COD, NH_3-N	--	--	COD, NH_3-N
11	--	COD, NH_3-N	COD, NH_3-N	NH3-N	NH_3-N	COD, NH_3-N
12	--	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N	COD, NH_3-N

Note: the water quality parameters here refer to the outlets or tributaries needed to control those pollutants. '--'expresses no pollution control strategy needed to be conducted in the given month; specific reduction can refer to previous calculations

The performance of WASP Model on November and December cannot be calibrated therefore WEC in this two month has large uncertainty. This is also a challenge for using traditional water quality modeling tool to manger the contaminant load in cold area. Moreover, accessing official river water quality data is challenged in China, especially for heavily contained rivers. We only have datasets in 2008-2013 which are based on a research project cooperated with local government. Therefore, this study is only able to use monitoring data 6 years ago to illustrate water quality management technology. The overall WEC in the Acheng Section is computed by adding the individual unit capacity. This method normally leads to exceeding water quality criteria over the whole control unit, although water quality at the controlled cross-section meets the WFZ criteria. Owing to the short lengths of segments and the lower rate of pollutant degradation, this excess can be ignored in management practices. In the future, the river water quality management in the winter season should take into particular consideration. The Chinese government will turn to the controlling end point of DO for surface water in the long run.

CONCLUSIONS

During the period of total load control pattern updating in China, local governments need to make river pollution control plans according to the river water environment capacity. For cold regions, a dynamic pollution control plan, either seasonal or monthly, is quite important. This work conducted a case study of pollution load reduction in the Ashi River in northeast China. Although many efforts have been made in the past decades, this river is still a highly contaminated river in the inner city of Harbin. Connected to water function zoning, two control units were defined in the study area Acheng District Section of the Ashi River. The actual and surplus water environmental capacity of COD_{Cr} and NH_3-N were computed using a WASP surface water quality model based on section-end-control method. It was found that the environmental capacity of COD_{Cr} and NH_3-N were 1707.16t/a, and 131.57t/a, respectively in the Zhujia-Acheng downriver reach for the year 2012. Similarly, the environmental capacity of COD_{Cr} and NH_3-N were 1061.75t/a, and 26.07t/a, respectively, in control unit 2, the reach between Acheng down and Chenggaozi town cross section. Specific characteristics of surplus water environmental capacity were observed. Some showed interesting fluctuations over the months. Monthly dynamic pollution control scheme was suggested for the year 2012. COD_{Cr} and NH_3-N of Zhujia-Acheng down should be reduced to 462.47t/a, and 462.47t/a, respectively, while the same contaminants for the reach between Acheng down-Chenggaozi town should be decreased to 282.42t/a, and 9.25t/a, respectively. Moreover, the COD_{Cr} and NH_3-N of Nanda, Chengnan and Haigou ditch should be strictly controlled. A seasonal control plan at each outlet and tributary can also be easily deduced from the current results. "Ten Regulations for Water" has token effect in China. This case study provides a useful pattern for updating the pollution control plan not only for the Harbin and Heilongjiang governments but also for the whole nation.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

a	Annual
BOD_5	5 days biochemical oxygen demand
CBOD	Carbonaceous biochemical oxygen demand
COD	Chemical oxygen demand
COD_{Cr}	Chemical oxygen demand measured by potassium dichromate method
COD_{Mn}	Chemical oxygen demand measured by potassium permanganate method
CU	Control unit of load reduction and planning
d	Day
DO	Dissolved oxygen
EPA	Environmental Protection Agency
$g/(m^2 \cdot d)$	gram per square meter per day
K_{COD}	Degradation coefficient of chemical oxygen demand
K_{NH3-N}	Degradation coefficient of ammonia nitrogen
m	Meter
mg/L	Milligram per liter
mgO_2/mgC	Milligram oxygen per milligram carbon
m/m	Meter per meter
NH_3-*N*	Ammonia nitrogen
SOD	Sediment oxygen demand
TMDL	Total maximum daily Load
ton	Ton per year
WASP	Water quality analysis simulation program
WEC	Water environmental capacity
WFZ	Water function zone
^oC	degree Celsius

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