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Short communication

Characteristics of a landscape water with high salinity in a coastal city of China and measures for eutrophication control

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ABSTRACT

Eutrophication of landscape waters is drawing public concerns in China but few studies have been conducted on the problem associated with high water salinity as what happens at Sino-Singapore Tianjin Eco-city in Tianjin, a coastal metropolis of northern China. In order to find ways for eutrophication control, a comparative study was conducted on three landscape water bodies, namely Qingjing Lake, Jiyun River and Jiyun River Oxbow, which are under varied conditions of salinity, organic, and nutrients intrusion. The spatial and temporal variations of water quality were revealed by water sampling and analyses, and correlative relationships were obtained between water salinity and other parameters related to eutrophication. By utilizing a trophic level index (TLI), the eutrophication status of the three landscape water bodies in different seasons could further be evaluated. As a result, water temperature, as expected, showed the strongest effect on eutrophication because higher TLI together with higher Chl-a concentrations tended to occur in later spring and summer seasons, while nutrient concentration, especially TP, was also the determinative factor to the eutrophication status. Of the three water bodies, the Jiyun River Oxbow showed a salinity as high as 20 g/L or more in contrast with the other two water bodies with salinity as 4–5 g/L. Although its TP concentration was usually very low (about 0.1 mg/L), it was under a moderate eutrophication status almost in all seasons, indicating that high salinity tends to induce alga growth. Dilution of saline inflow and nutrients reduction could thus be proposed as the main measures for eutrophication control of landscape waters in the study area.

1. Introduction

With the rapid development of economy and the improvement in people's living standards, more and more attentions have been paid on the urban ecological environment improvement. Construction and/or restoration of landscape waters are often an important part of urban water elements, not only for beautifying the urban environment, but also providing ecological oxygen sources and atmospheric humidity to the urban zone. Landscape water plays an important role in regulating precipitation, supplementing water resource, reducing the heat island effect, and enhancing the human power against disasters and plagues. Because most of the urban landscape waters are enclosed or semi-enclosed water bodies, their self-purification capacity is weak. When the water bodies receive excessive nutrients, eutrophication may easily happen (Chen et al., 2013; Henny and Meutia, 2014). Impairment of water quality due to eutrophication can lead to a series of problems and result in losses of ecological integrity, sustainability and safe use of aquatic ecosystems (Yu et al., 2014). Although eutrophication of landscape waters has been widely and intensively studied for several decades ((Istvánovics, 2009; Liu et al., 2014), few experiences have been gained on eutrophication control associated with high water salinity, as what often happens in coastal cities, because salinity may also be an indicator of trophic conditions (Gasiūnaitė et al., 2005).

In the northern coastal metropolis, Tianjin, the Sino-Singapore Tianjin Eco-city has been under construction in the coastal zone of the Bohai Sea. An important component of the eco-city construction is the restoration of a water area mainly consisting of three closed or semi-closed water bodies. Due to the limited catchment area and very low rainfall in these regions, these water bodies cannot be well replenished and increasing water salinity is a problem under concern. In order to find ways to cope with the current problem and envisaged problem in the future, a comparative study was conducted on the water quality and eutrophication status of the three water bodies. Attention was paid on the influence of water salinity on eutrophication and the possible measures for eutrophication control.

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2. Materials and methodology

2.1. Study area

Sino-Singapore Taijin Eco-city (N 39°5′14″–39°8′45″, E 117°43′34″–117°46′48″) is located in Tianjin Binhai New Area, which is only 1 km away from the Bohai Sea coastline. Qingjing Lake and Jiyun River, as important parts of Sino-Singapore Eco-city's surface water system, are the typical landscape waters under the influence of saline intrusion in China. The Qingjing Lake is with about 1.1 km^2 water surface and on average about 2 m in depth, and the Jiyun River Oxbow is with a water surface of 2.88 km^2 and an average depth about 2.3 m. At present, Jiyun River Oxbow is a closed water body, and Qingjing Lake is a semi-closed water body. A tidal gate has been installed to separate the Jiyun River Oxbow from another water body at its upstream, which is the Jiyun River as a closed water body in most time throughout the year. In addition to the occasional rainfall, these water bodies receive limited supplemental source on 'as needed' basis from sea water desalination and a reservoir.

2.2. Sample collection and analyses

As shown in Fig. 1, 7 sampling points were selected for collecting water samples from these landscape waters, 1 for Jiyun River Oxbow, 4 for Qingjing River, and 2 for Jiyun River. Monthly water quality monitoring was conducted from November 2013 to June 2014 regarding TP using molybdenum antimony spectrophotometry, TN using alkaline potassium persulfate digestion UV spectrophotometry, Chl-a using acetone extraction spectrophotometry, water transparency using a Plug's disk, COD using permanganate method and BOD$_5$ using dilution and inoculation method. Portable instruments were also used for measuring conductivity, TDS, pH and temperature. Correlation analysis was conducted by using SPSS 17.0 software.

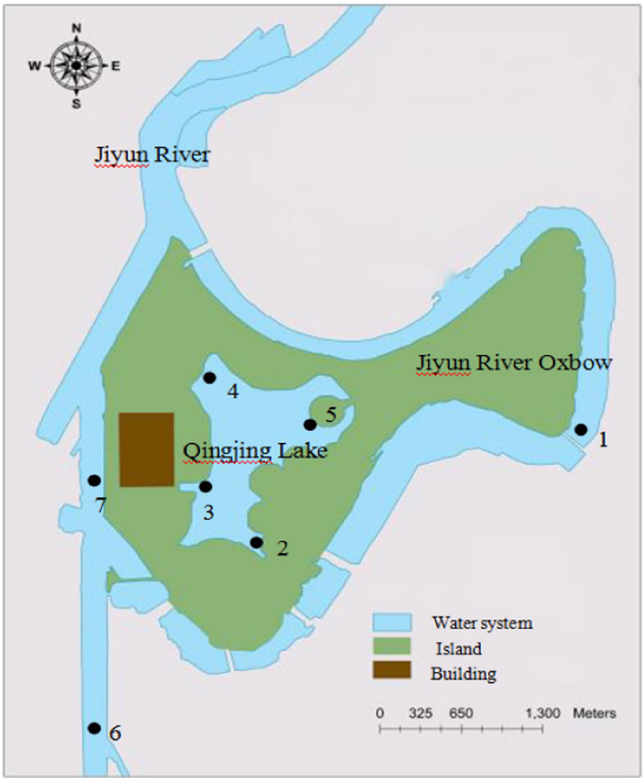

Fig. 1. Location map of the sampling points.

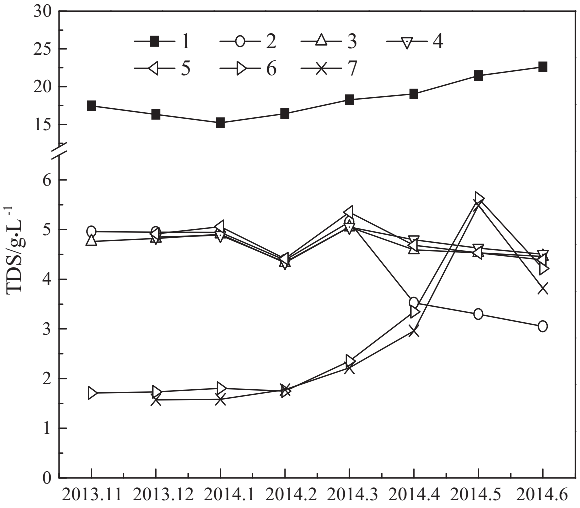

Fig. 2. Spatial and temporal variation of TDS content.

3. Spatial and temporal variation of water quality

3.1. Variations of water salinity

Because the study area is located in the Binhai New Area and the salinity is high in the soil, the salt content in the landscape waters is high as well (Xiao-wen et al., 2013). As shown in Fig. 2, Jiyun River Oxbow showed the highest TDS content, ranging from 15.19 to 22.59 g/L, which was mainly due to the tidal intrusion, resulting in salt accumulation in water and soil of the oxbow. The TDS content of Qingjing Lake was much lower, ranging from 4.33 to 5.53 g/L and with unobvious seasonal variation, which was due to the replenishment using desalinated water, resulting in effective salinity reduction in water and soil. The TDS content of Jiyun River varied between 1.62 and 5.56 g/L, tended to increase after winter and early spring, and reached the peak in May. The intrusion of high salinity water from downstream side through the gate was the reason for the TDS increase.

3.2. Variation of TN and TP

As shown in Fig. 3, the TN content of Jiyun River was higher than that of Jiyun River Oxbow and Qingjing Lake. For Jiyun River, the TN concentration varied with time and two peaks appeared in January

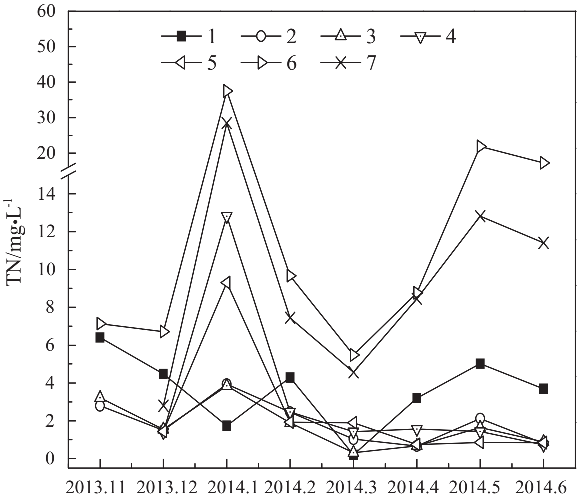

Fig. 3. Spatial and temporal variation of TN content.

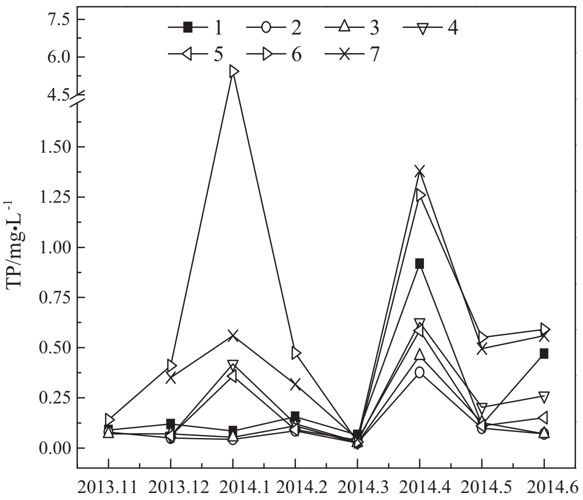

Fig. 4. Spatial and temporal varioation of TP content.

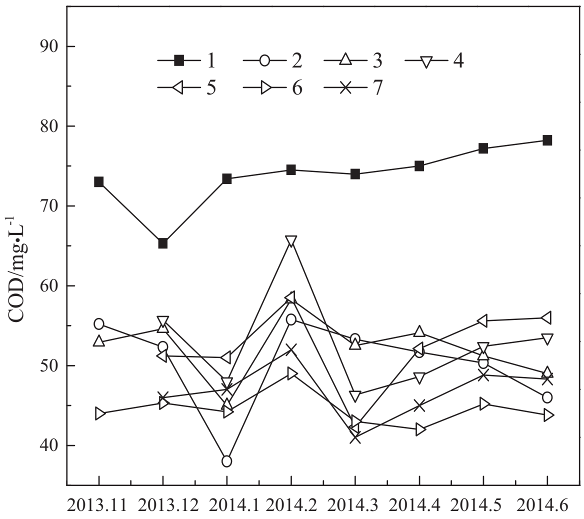

Fig. 5. Spatial and temporal variation of COD content.

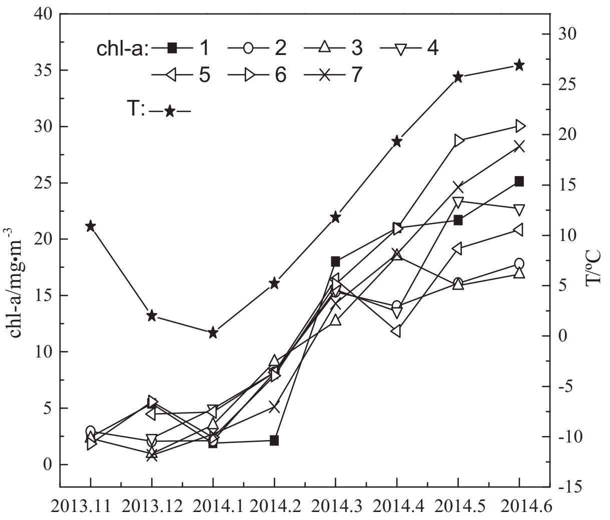

Fig. 6. Spatial and temporal variation of Chl-a content and water temperature.

and May as 37.5 mg/L and 21.8 mg/L, respectively. The TN content of Jiyun River Oxbow was relatively low and the highest concentration was 6.4 mg/L in November. For Qingjing Lake although TN concentration was low in most months, a high concentration of 12.8 mg/L was detected in January.

The spatial distribution of TP content is shown in Fig. 4. Generally speaking, Jiyun River showed higher TP concentrations than the other two water bodies and two peaks appeared in January and April as 5.59 and 1.32 mg/L, respectively. For Qingjing Lake, two peaks also appeared in January and April but showed much lower TP concentrations of 0.42 mg/L and 0.63 mg/L respectively. TP concentration in Jiyun River Oxbow was usually low in the study period while a peak of 1.37 mg/L appeared in April.

In addition to TN and TP concentrations, the N/P ratio may also indicate the potential of algae growth. For a closed or semi-closed water body, at $N/P < 14$, nitrogen may be the limiting factor for algae growth, while at $N/P > 14$, phosphorus can be regarded as the limiting factor (Daines et al., 2014). From the monitoring results, the N/P ratio always varied between 25.3 and 39.4, which were much larger than 14. Therefore, phosphorus was identified to be the limiting factor of algae growth in these water bodies.

3.3. *Variation of COD*

Fig. 5 shows the spatial distribution of COD content of the three water bodies. The tendency was in general similar to that for TDS, namely with higher COD appearing in waters with higher TDS concentration. The COD content of Jiyun River Oxbow was the highest all the time and increased gradually to 78.2 mg/L in June. The COD content of Qingjing Lake fluctuated between 38 mg/L and 65.75 mg/L, while the COD content of Jiyun River was relative stable with a slight variation between 41 mg/L and 49 mg/L. On the whole, the COD content of each water body did not vary largely in the observation period. This might be an indication that organic substances may be poorly biodegradable in saline waters nor easily absorbed by plants. The BOD_5/COD ratio was in fact as low as 0.1–0.2, which is the evidence of the poor biodegradability of organics in these waters (Cossu et al., 2012).

3.4. *Variations of Chl-a*

As shown in Fig. 6, the distribution of Chl-a contents coincided much with that of TN and TP, namely higher Chl-a content in Jiyun River followed by Jiyun River Oxbow and Qingjing Lake. However Chl-a content showed a tendency of increase with increasing water temperature. As expected, in winter season Chl-a content was low because low temperature of water was unfavorable for algae growth, especially in January. After winter season, Chl-a content increased gradually and reached high values in summer time, partially due to the higher temperature, and partially due to the increased sunlight radiation to assist the utilization of the accumulated nutrients since winter (Figs. 3 and 4) for algae growth. The higher Chl-a contents in Jiyun River was also due to the intrusion of seawater from the downstream gate which resulted in higher nitrogen and phosphorus contents to promote algae growth.

4. Correlation analysis of water quality index

4.1. *Correlative relation between COD and TDS*

Significant correlation between COD and TDS in water has been reported in some studies (Al-Omari et al., 2013). By analyzing the data in each of the four seasons, significant positive correlations were found between COD and TDS concentrations of these waters especially in spring, summer and autumn seasons where high correlative coefficients were obtained as shown in Table 1. Therefore, for saline landscape waters, the simple TDS measurement may provide a rough estimation of the COD level.

Table 1
Correlative relation between COD and TDS in each season.

Autumn	Winter	Spring	Summer
0.978**	0.795**	0.928**	0.945*

** Significantly correlated under level 0.01 (bilateral).
* Significantly correlated under level 0.05 (bilateral).

Table 2
Correlative relation between pH and TN, TP, Chl-a in each season.

	pH			
	Autumn	Winter	Spring	Summer
TN	−0.977*	−0.495	−0.573**	−0.492
TP	−0.686	−0.252	−0.407*	0.059
Chl-a	−0.124	−0.367	−0.587**	−0.859*

** Significantly correlated under level 0.01 (bilateral).
* Significantly correlated under level 0.05 (bilateral).

Table 3
Correlative relations between Chl-a and TN, TP, TDS in each season.

	Chl-a			
	Autumn	Winter	Spring	Summer
TN	−0.112	0.683**	0.420*	0.502
TP	−0.104	0.668**	0.252	−0.074
TDS	−0.298	−0.332	−0.154	−0.14

** Significantly correlated under level 0.01 (bilateral).
* Significantly correlated under level 0.05 (bilateral).

4.2. Correlative relation between pH and TN, TP, Chl-a

The pH of the landscape waters varied between 8.3 and 9.5 in the monitoring period, indicating a slightly alkalescent condition. In such a pH range, significant correlations were not found between pH and other parameters such as TN, TP and Chl-a. As shown in Table 2, most of the correlative coefficients obtained were negative and comparatively significant correlations were only found between pH and TN in autumn, and between pH and Chl-a in summer. However, TN, TP and Chl-a correlated evidently with pH in spring. Only Chl-a shows a significant correlation with pH in summer. Although pH has been pointed out as an important factor to affect algae growth (De-jin et al., 2010), it may not be very significant in the case of saline landscape water.

4.3. Correlative relation between Chl-a and TN, TP, TDS

To a certain degree, Chl-a is an indicator of algae growth in water. Table 3 shows the correlative relations between Chl-a and TN, TP, TDS in each season. It can be seen that negative correlations existed between Chl-a and TN, TP and TDS in autumn, while positive correlations existed between Chl-a and TN, TP in winter and spring. Although not significant, Chl-a was positively correlated to TN but negatively correlated to TP in summer. It is also noticeable that Chl-a showed negatively correlations with TDS in all seasons, which might be an indication of the inhibitory effect of TDS on algae growth (Wu et al., 2011).

4.4. Comprehensive evaluation of eutrophication status

Based on the water quality monitoring data, a comprehensive evaluation of the eutrophication status of each landscape water in each season were conducted using the comprehensive nutrition state index method (Israël et al., 2014). As shown in Fig. 7, of the three landscape water bodies, Qingjing Lake showed a good condition almost throughout the whole year because its TLI values were mostly lower than 60 which is the threshold of mild eutrophication status. The highest TLI value for Qingjian lake was about 60.5 in winter. However, as can be seen from Fig. 6, the winter season may not be a time for algae bloom. Therefore, eutrophication control for Qingjian Lake may not be a heavy task.

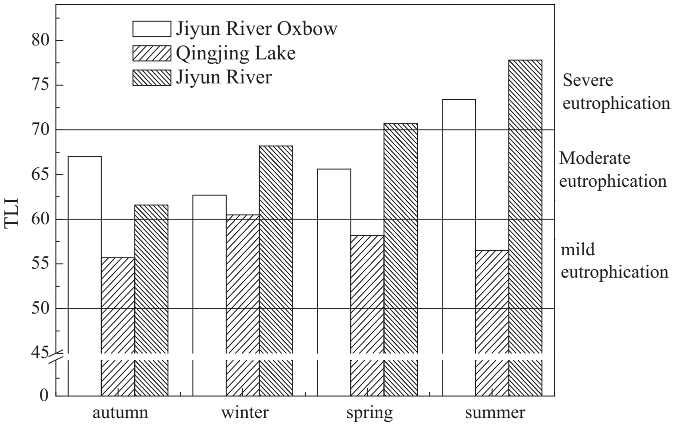

Fig. 7. Comprehensive evaluation of eutrophication status of each water body in each season.

Regarding Jiyun River Oxbow, its TLI values were higher than 60 but lower than 70 in autumn, winter and spring seasons, indicating a moderate eutrophication status. However, the TLI value in summer was about 74 which indicates a severe eutrophication status. As algae growth may easily occur in summer season, effective measures may have to be taken for eutrophication control for Jiyun River Oxbow.

The condition of Jiyun River was the most unfavorable of the three water bodies because its TLI values were higher than the other two water bodies in most seasons. In autumn and winter, it showed moderate eutrophication status but in spring and summer, it became severe eutrophication status especially in summer when TLI became as high as about 78. Therefore eutrophication control may be a heavy task for Jiyun River.

5. Formulation of a plan for eutrophication control

5.1. Relationship between water quality parameters and eutrophication status

Following the discussion in former sections, Table 4 can be obtained to summarize the relationship between water quality parameters and eutrophication status of the three water bodies.

Of the three water bodies, Qingjing Lake generally showed mild eutrophication status in the study period, and relatively low TP concentration (<1 mg/L), low TN concentration (<4 mg/L) and moderate salinity (4–5 g/L) are the main characteristics of water quality. In contract to this, Jiyun River Oxbow is a typical saline water body (TDS > 15 g/L). Although its TP concentration (about 0.1 mg/L) was lower than that of the Qingjing Lake, it showed moderate eutrophication status. Higher TN concentration (>6 mg/L) may contribute to this but because TP is recognized to be the limiting factor for these waters, the moderate eutrophication status is thought to be greatly resulted from its high salinity. As for Jiyun River which was also with moderate salinity (about 4 g/L), the severe eutrophication status is mainly due to its high TP concentration (>1 mg/L).

If we compare the Qingjing Lake with Jiyun River Oxbow, the more eutrophic condition of the later is apparently due to its higher salinity but not the TP concentration. Anyway, higher TP concentration would definitely bring about severer entrophication such as the Jiyun River which showed a salinity similar to the Qingjing

Table 4
Summary of water quality and eutrophication status of the three water bodies.

Parameters	Qingjing Lake	Jiyun River Oxbow	Jiyun River
TDS	4–5 g/L	>15 g/L	Approximately 4 g/L
COD	40–60 mg/L	70–80 mg/L	<60 mg/L
TN	<4 mg/L (Occasionally high)	<6 mg/L	>6 mg/L (occasionally very higher)
TP	<1 mg/L (Occasionally higher)	0.1 mg/L (Occasionally higher)	>1 (frequently)
Chl-a	Higher in spring and summer	Higher in spring and summer	Higher in spring and summer (the highest)
TLI	Mild eutrophication	Moderate eutrophication	Occasionally severe eutrophication

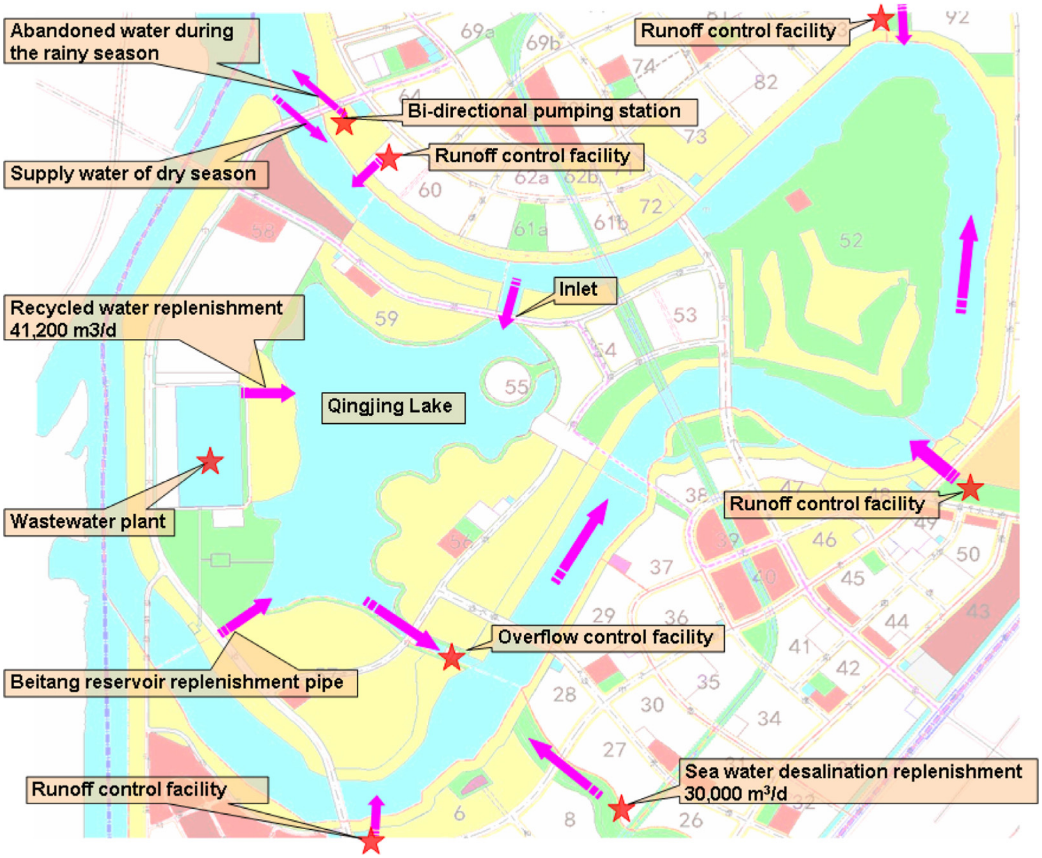

Fig. 8. Comprehensive plan for salinity and nutrients reduction.

Lake. Therefore, for eutrophication control in the study area, both salinity and nutrients reductions should be taken into account.

5.2. *A comprehensive plan for salinity and nutrients reduction*

Fig. 8 is a comprehensive plan for integrating the three water bodies into a surface water system with a number of facilities to perform the roles of salinity reduction, nutrients intrusion control, as well as water flow regulation, under consideration of the current salinity and nutrients levels in each water body and the availability of low-salinity water sources.

As shown in the figure, the reduction of water salinity is to be performed mainly by fresh water replenishment using reservoir water, desalinated water, and reclaimed water from nearby sources. Because Tianjin is among the most water-deficient cities in northern China, continuous supply of water for landscape purpose would be very difficult. Therefore, the operation of the planned water replenishment facilities will be on an "as needed" basis following the outcome from the present study. In principle, the reduction of water salinity can be achieved by freshwater dilution and/or saline water discharge. A bi-directional pumping station is thus planned for pumping water in between the currently very saline Jiyun River Oxbow and moderately saline Jiyun River, so that salinity adjustment can be performed between the two water bodies.

On the other hand, fresh water replenishment can also bring about substantial reduction of nutrients in the water bodies. However, as surface runoff is the major local nutrients source, runoff control facilities will be provided to assist the reduction of nutrients intrusion. Because TP is recognized to be the limiting factor for eutrophication, phosphorus removal by chemical precipitation is also proposed as a measure for TP reduction from the runoff flow.

Although it is not the topic for the present study, water circulation between and within these water bodies are also an important measure for eutrophication control. As shown by the arrows in Fig. 8, flow regulation to promote water moving along the planned directions is considered as well.

6. Conclusions

Eutrophication of landscape waters of elevated salinity is a special topic for investigation. Taking Sino-Singapore Tianjin Eco-city as a typical case, water quality monitoring was conducted for three water bodies in the same area but with different saline conditions. It is noticeable that in addition to nutrients, water salinity has strong effect on the eutrophication status of a water body. With higher water salinity, eutrophication tends to occur easier even the nutrient level (especially TP in this case) is not sufficiently high. Therefore, salinity and nutrients reduction may be equally important for landscape waters under the threat of salt intrusion. The findings from the present study can assist the formulation of a rational plan for eutrophication control as what has been done in the study area, and also enrich the knowledge on eutrophication problems relating to saline waters.

Acknowledgements

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