Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.830803

52 (2014) 5015–5020
July

Taylor & Francis
Taylor & Francis Group

Wastewater reclamation for various non-potable supplies and water quality control in a minimum-emission hydrologic cycle

Rong Chen*, Xiaochang C. Wang, Kun Wu, Yongmei Zhang, Yisong Hu

Key Lab of Northwest Water Resource, Environment and Ecology, MOE, Xi'an University of Architecture and Technology, Xi'an 710055, China
Email: chenrong@xauat.edu.cn

Received 29 November 2012; Accepted 10 July 2013

ABSTRACT

In this study, we implemented an isolated decentralized water system with minimized wastewater discharge and maximized water reuse in water-deficient region. Dual quality wastewater reclamation and reuse system with parallel conventional treatment unit and advanced MBR treatment unit was built in which the reclaimed water with normal quality and high quality was produced, respectively. Based on maximum collection of the recollectable discharged water, the minimum-emission scheme characterized by high cycling rate of the limited water resource was formed and consequently all the nonpotable water consumption was covered by the reclaimed water. Environmental lakes integrated with multifunctions of quantity regulation and quality stabilization of the reclaimed water were introduced in the system configuration and stepwise use of the reclaimed water was observed successfully. As a result of the system operation, main pollutants were well removed and the quality of reclaimed water can reach the demands of various non potable reuse purposes. Water bodies on campus prove to be of good quality of surface water. The project accomplished the minimum emission of discharged water and maximum use efficiency of water resource. It was proven to be feasible based on the technical and economic evaluation. This study provided a model case for future urban development in the water-deficient regions.

Keywords: Wastewater reclamation; Non-potable supplies; Minimum-emission

1. Introduction

Wastewater reclamation and reuse has become an important way for mitigating water shortage in arid areas worldwide [1]. Decentralized wastewater treatment and reuse system has showed its advantages in suburb areas which are far from the central city [2]. An isolated hydraulic cycle with onsite water supply, collection, treatment, and reuse tends to be possible in some regions where the centralized water supply and drainage system is unavailable. Optimized water system with harmonic integration of water supply, sewerage, water reuse, and waterfront landscape is a

*Corresponding author.

Presented at the Conference on Water Resources and Urbanization Development, 26–27 September 2012, Tianjin, China

1944-3994/1944-3986 © 2013 Balaban Desalination Publications. All rights reserved.

key point to increase water use efficiency and to achieve maximized wastewater reuse in the isolated hydraulic cycle. Water quality stabilization and control is also quite important to configure a sustainable water system in this kind of closed or semi-closed water cycle [3].

In this study, a decentralized water system of wastewater reclamation for various nonpotable supplies and water quality control was proposed that is to be applied in an isolated case site in northwestern China which faces severe water shortage problem [4]. The research objective is to increase regional water use efficiency and decrease wastewater/waste discharge by water system configuration/optimization integrating fresh water supply, sewerage, reclaimed water use, and waterfront landscape. Xi'an Siyuan University (XASU), a private university located in the southeast suburban area of Xi'an, was selected as the pilot project. The university campus is on a hill about 13 km from the central city and with average elevation 200 m higher than the surrounding area. In this condition, an isolated water system is supposed to be established without any connection with urban centralized water supply and sewerage facilities. Since the water supply depends on the limited groundwater, the objectives of the water system establishment and construction are to configure a minimum-emission hydrologic cycle of wastewater reclamation for various nonpotable supplies as well as water quality control. Attentions were especially paid to the treatment technology selection and reuse scheme options which influence the reclaimed water quality and consumption.

2. Material and methods

2.1. Dual-quality wastewater reclamation

Potable uses, garden irrigation, road washing, indoor nonpotable uses (mainly toilet flushing), and lake replenishment are the main water use purposes in the university campus. The population of the university is 25,000 and the potable water consumption is calculated as around 2,500 m^3/d (100 L/d per person) [5], consequently the fresh water (groundwater, maximum capacity 3,000 m^3/d) can only be used for potable water supply. All the nonpotable uses including garden irrigation, road washing, toilet flushing, and lake replenishment must be supplied with reclaimed water.

Nonpotable uses in the campus were identified into two categories due to its different exposure levels to human beings and requirement for reclaimed water quality. One is called "high exposure" reuse purposes such as toilet flushing, landscaping, and sprinkle irrigation, which should be supplied with high-quality reclaimed water. The other is called "low exposure" reuse purposes, such as ordinary irrigation and gardening, which can be supplied with normal/low-quality reclaimed water [6].

A dual-quality wastewater treatment and reclamation station was built in the university campus. As shown in Fig. 1, two separate treatment units were constructed; one of which employs a conventional biological treatment followed by coagulation, sedimentation, and filtration with a capacity of 1,500 m^3/d to produce normal-quality reclaimed water for gardening and road washing and the other employs a membrane

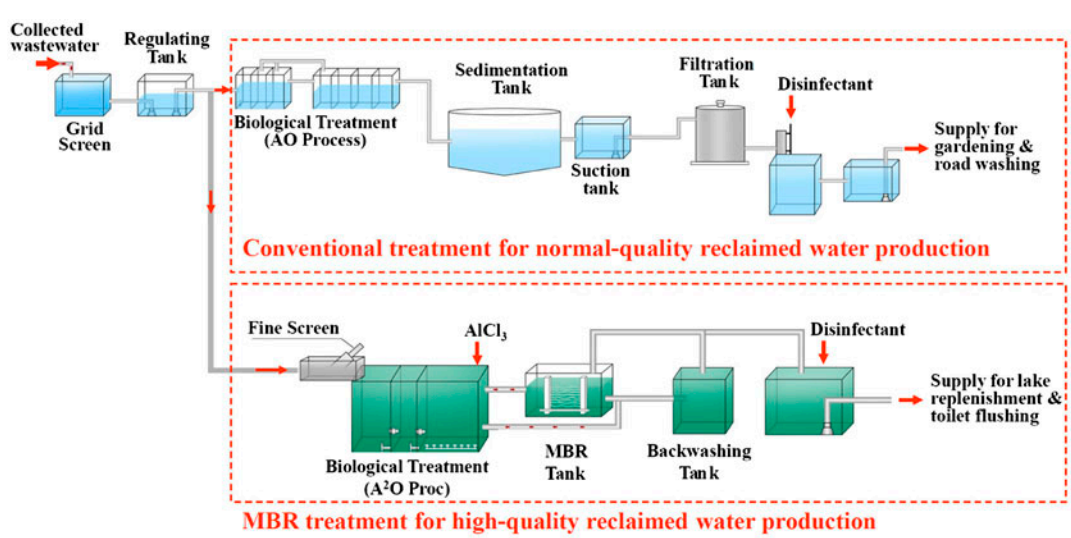

Fig. 1. Dual-quality wastewater treatment and reclamation units.

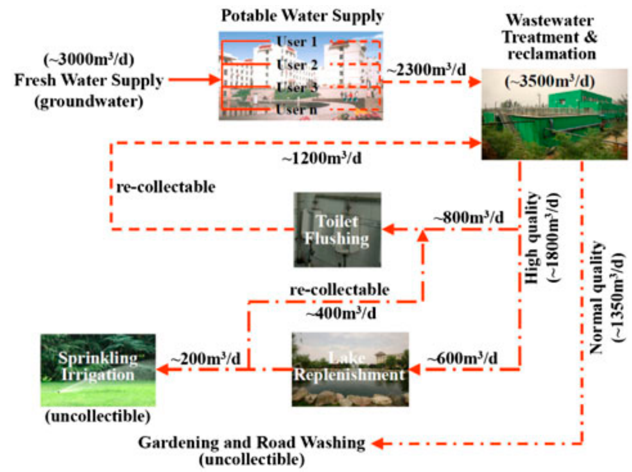

Fig. 2. Scheme of water reclamation and reuse in the campus.

bioreactor with a capacity of 2,000 m^3/d to produce high-quality reclaimed water for landscaping and toilet flushing [7]. Treated wastewater was disinfected before being supplied to different reuse purposes, respectively.

2.2. Reclaimed water stepwise use

In order to increase water use efficiency, it is necessary to balance the quantities of water reuse supplies for different purposes. As a kind of means, increasing the cycling rate of the limited water resource through maximized recycling the recollectable used water was proposed and implemented. As Fig. 2 shows, the groundwater is merely used for potable and miscellaneous uses and approximately 2,500 m^3/d used water will be discharged into the wastewater collection system and then sent to the wastewater treatment units. On the other hand, in the process of reclaimed water reuse, the reclaimed water for gardening and road washing (including sprinkling irrigation) is uncollectable after use while that for toilet flushing (around 1,200 m^3/d) will be discharged into the wastewater collection system again and be added to the influent to the wastewater treatment units. Therefore, the total influent flow of wastewater treatment will become around 3,500 m^3/d which can satisfy all the demands of nonpotable water consumption in the campus, thus the cycling rate of water resource amounts to 40%. As a result, the total water demands calculated as 6,150 m^3/d (including potable demands 3,000 m^3/d and nonpotable demands 3,150 m^3/d) can be satisfied by the 3,000 m^3/d limited fresh water supply, thus the water use efficiency amounts to 200%.

In order to keep good water quality, especially the quality of the water bodies in campus, stepwise use of reclaimed water was constructed among the water bodies and other reuse purposes. As Fig. 3 shows, high-quality reclaimed water from MBR treatment unit is, respectively, pumped into several small water

Fig. 3. Scheme of stepwise reclaimed water use system.

bodies and Siyuan Lake in the upstream. The reclaimed water also flows into Siyuan Lake in the upstream by gravity after short retention time in the three small water bodies named "Reading Benefit," "Stone Alchemy," and "Time and Tide." Siyuan Lake, which is composed of tree interconnected small lakes, is the main water body. In the system, Siyuan Lake is utilized as the environmental lake where the hydraulic condition in each lake is as below:

(1) Lake 1 receives the reclaimed water sourced from its eastern outlet and from "Reading Benefit" and "Stone Alchemy." The central fountain of the lake performs effective aeration. On the edge of the western side, water overflows to the northern end of Lake 3. The water can also be pumped from the southern side of Lake 1 to the rockwork mounted at the northern side of Lake 2. In this way, a continuous flow is kept in Lake 1.

(2) Lake 2 receives the reclaimed water sourced from its southeastern inlet and from "Time and Tide," plus the water pumped from Lake 1 through the rockwork which forms a waterfall (about 5 m in height) and meanwhile plays the role of aeration. Aquatic plants grow in Lake 2 and cover most of the lake surface. The outlet of Lake 2 is another waterfall (about 1 m in height) where water flows to the adjacent Lake 3. There is also an inlet at the southern side of Lake 2 to receive harvested rainwater. The retention time of water in Lake 2 is relatively short due to its smaller surface area and storage volume.

(3) Lake 3 is virtually a water passage where water coming from Lake 2 flows from one end to the outlet near the other end, while water coming from Lake 1 flows directly through shortcut to the outlet. From the outlet, water flows to two pump stations, one supplying water for sprinkling irrigation of the green belt in the central yard, and another supplying water to the main teaching buildings and the university library for toilet flushing.

Based on the above arrangement, waterfront landscape on campus principally does not consume much water, because the water is successively reused for toilet flushing and/or sprinkling irrigation after landscaping use. The escalated water reuse scheme brings about highly efficient utilization of the reclaimed water. The quantity of the reclaimed water entering the environmental lakes is automatically controlled by the water consumption for toilet flushing and

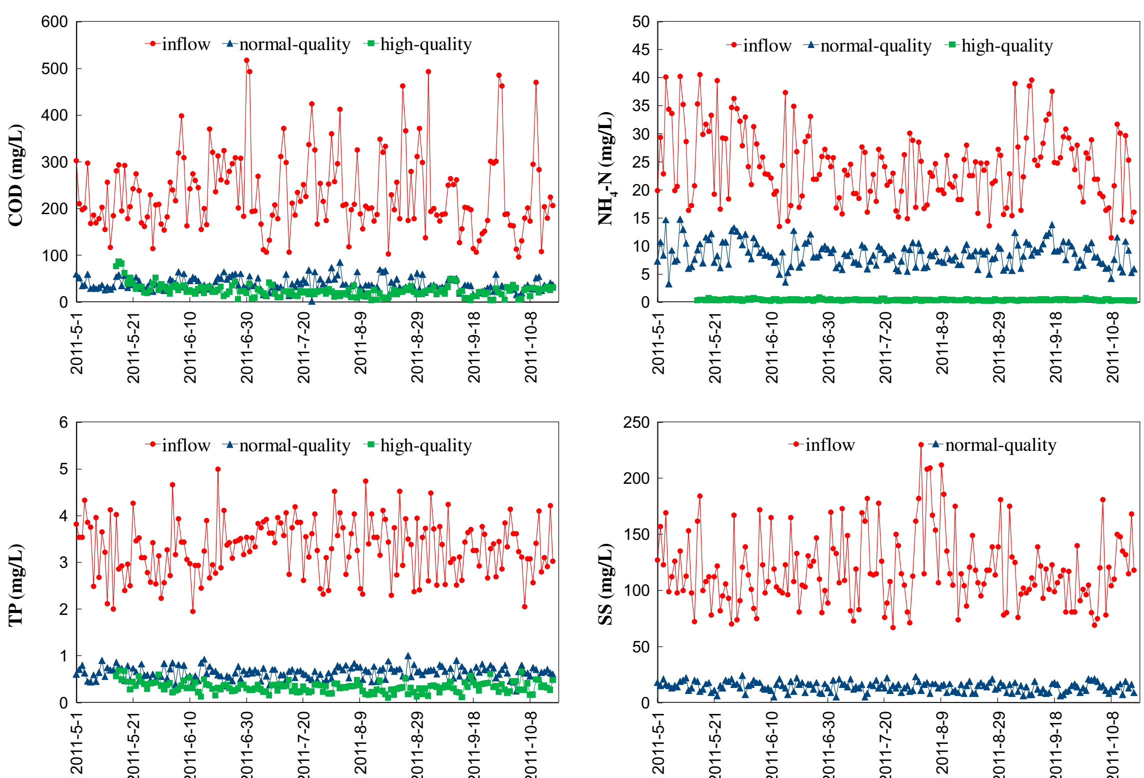

Fig. 4. Pollutants' removal in the dual-quality wastewater reclamation units.

sprinkling irrigation. With an effective volume of more than 3,000 m^3, the lakes become an ideal buffer zone and regulation reservoirs in the water reuse system. With the stepwise use of reclaimed water, the total water retention time in water bodies is limited to no more than five days. The environmental lakes can also play self-purification of water quality by a series of processes such as UV radiation through the sunlight and physicochemical and/or biological actions through water plants, sediments, and bottom materials.

3. Results and discussion

3.1. Pollutant removal in wastewater reclamation units

Fig. 4 shows the average removal of the main pollutants in the dual-quality wastewater treatment and reclamation units under the standard operational condition. The removal rate of COD, SS, NH_4-N, and TP amounts to 84, 88, 65, and 81% in the conventional wastewater reclamation unit and the average concentration in the effluent is 38, 14, 8.6, and 0.6 mg/L, respectively. The treated wastewater (normal-quality reclaimed water) appears to meet the Chinese Standard of criterion for urban gardening and road washing [8]. Comparatively, the removal rate of COD, NH_4-N, and TP amounts to 90, 98, and 90% in the membrane bioreactor reclamation unit and the average concentration in the effluent is 24, 0.4, and 0.3 mg/L, respectively. SS concentration in the effluent is too low to detect. The treated wastewater (the high-quality reclaimed water) from membrane bioreactor reclamation unit showed remarkable pollutants' removal rate and surpassed the Chinese Standard of criterion for landscaping [9].

3.2. Water quality control in water bodies

Fig. 5 shows the main pollutants' concentration behavior in Siyuan Lake from the end of May to the middle of October 2011. In the particular situation that the lake was replenished absolutely by the reclaimed water, the main pollutants' concentration of COD, NH_4-N, and TP retained at a low level and the average concentration of dissolved oxygen in the lake water was always over 5.0 mg/L. As Fig. 5 shows, surface water quality was categorized into five grades in China according to water quality condition in the surface rivers/lakes [10], in which water quality condition of Grade III is the basic requirement

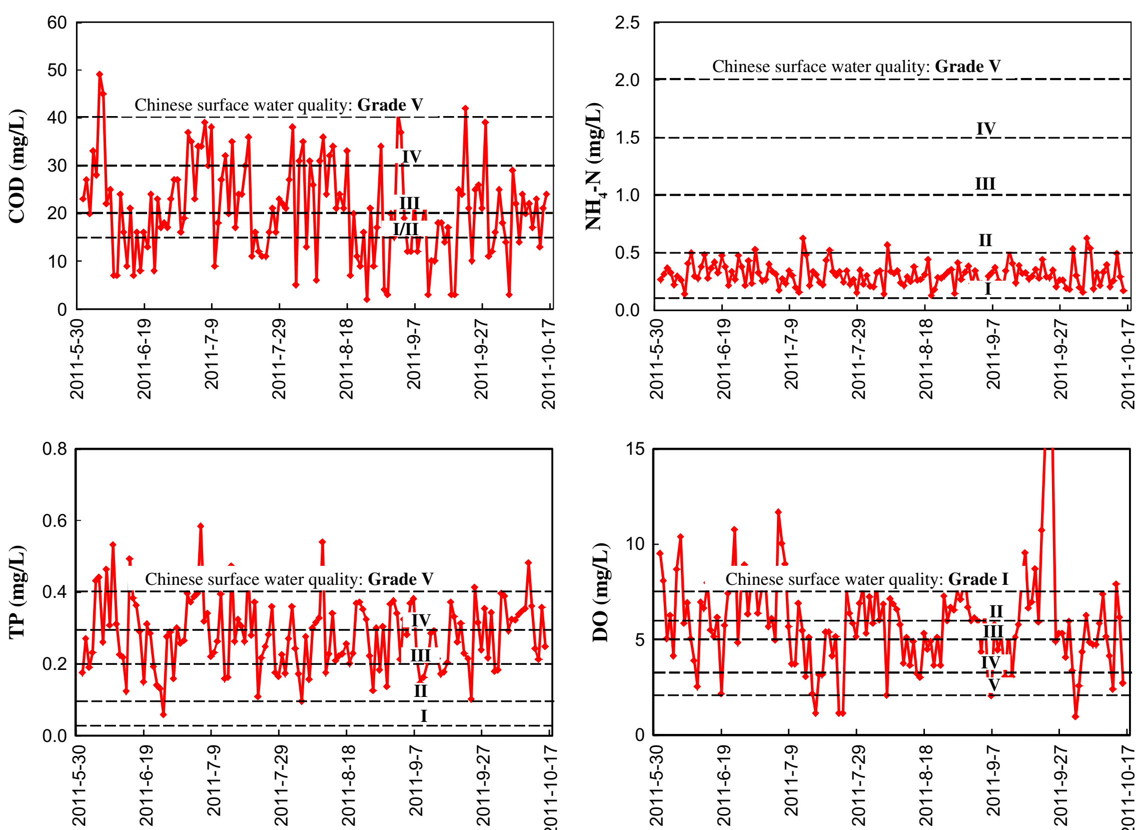

Fig. 5. Main pollutants concentration in the Siyuan Lake.

for drinking water supply and that of Grade V is the basic requirement suitable for landscapes replenishment. Fig. 5 indicates that the water quality index of COD, NH_4-N, TP, and DO in Siyuan Lake can reach Grade V requirement of Surface Water Quality in China.

3.3. Minimum-emission hydrologic cycle operation

In XASU, the green belt area covers about 50 ha, which accounts for 60% of the whole campus area. As a result of implementing the project, the large green area is completely sustained by the reclaimed water. In addition, the reclaimed water also sustained the waterfront landscape of about 5,000 m^2 lake area on campus and hard surface (roads and squares) washing of about 10 ha. All these make the campus green and beautiful, and provide a comfortable environment for students and faculties to live, work, and study there.

As a result of water balance calculation, the demand for gardening and road washing is 1,375 m^3/d, which can be covered by the production of normal-quality reclaimed water and the demand for landscaping, and toilet flushing is 1,800 m^3/d which can be covered by the production of high-quality reclaimed water. That is to say, the total demand for nonpotable water use amounts to 3,175 m^3/d which can be sufficiently covered by the production of reclaimed water. On the campus, minimum-emission and maximized reclaimed water reuse was realized by dual-quality wastewater reclamation for various nonpotable water supplies, which makes it possible to meet the demand of more than 6,000 m^3/d water supply by only consuming 3,000 m^3/d freshwater resource.

Based on the operation experience last year, the unit operation/maintenance cost for the production of high-quality reclaimed water, i.e. from the MBR treatment unit, is estimated as 1.55 RMB/m^3 (including 0.7 RMB for electricity, 0.25 RMB for chemicals, 0.17 RMB for labors, and 0.43 RMB for membrane renewal as 5-year lifetime was referred) while that for the production of normal-quality reclaimed water, i.e. from the conventional treatment unit, is 0.8 RMB/m^3. Compared with the current tap water tariff of 3.95 RMB/m^3, the cost is worthwhile from the viewpoint of net economic benefit. By achieving minimum-emission, the required payment for pollutants' emission (0.7 RMB/m^3 on average) to the public sewer is also saved, resulting in larger economic benefit.

4. Conclusions

In this study, wastewater reclamation for various nonpotable supplies and water quality control in a minimum-emission hydrologic cycle was implemented in XASU, which is a typical isolated region in water-deficient city in northern China. By the configuration of dual-quality wastewater reclamation and reclaimed water stepwise use, wastewater minimum-emission, effective utilization of water resource, dual water supply, and water environment quality guarantee were realized. The project was proven to be feasible based on the technical and economic evaluation. This study provided a model case for future urban development in the water-deficient regions.

Acknowledgment

This study is sponsored by the China National Program of Water Pollution Control (Grant No. 2012ZX07313001-002), Shaanxi Provincial Program for Science and Technology Development (No. 2013KJXX-55), and Program for Innovative Research Team (No. 2013KCT-13).

References

[1] A. Takashi, F.L. Burton, H.L. Leverenz, R. Tsuchihashi, G. Tchobanoglous, Water Reuse: Issues, Technologies and Applications, Metcalf & Eddy | AECOM, New York, NY, 2007, pp. 36–50.

[2] P. Lens, G. Zeeman, G. Lettinga, Decentralised Sanitation and Reuse, IWA, London, 2004.

[3] X.C. Wang, L. Luo, R. Chen, H.H. Ngo, Thermodynamic analysis of an urban water system with reclaimed water as supplemental water resource, Desal. Water Treat. 32 (2011) 307–315.

[4] J. Cui, C. Jiang, A sustainability strategy of integrated highway wetlands for urban water management in China. Desal. Water Treat., doi: 10.1080/19443994.2013.780693.

[5] Shaanxi Water-saving Division, Capita water quota in universities and colleges, Urban life and public water quota of Water Quota of Shaanxi Province, China, 2004.

[6] S. Weber, S. Khan, J. Hollender, Human risk assessment of organic contaminants in reclaimed wastewater used for irrigation, Desalination 187 (2006) 53–64.

[7] L. Rodriguez-Hernandez, M. Gonzalez-Viar, L. De Florio, I. Tejero, Hybrid membrane bioreactor application for decentralized treatment and reuse, Desal. Water Treat. 51 (2013) 2467–2473.

[8] Standardization Administration of China (2002a). Reuse of recycling water for urban: Water quality standard for urban miscellaneous water consumption (GB/T 18920–2002).

[9] Standardization Administration of China (2002b). Reuse of recycling water for urban: Water quality standard for scenic environment use (GB/T 18921–2002).

[10] EPA of PRC. Chinese Surface Water Quality Standard (GB 3838–2002).