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Decentralised wastewater reclamation systems in Beijing – adoption and performance under field conditions

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Abstract
To alleviate water-scarcity, Beijing has an integrated strategy on water-recycling involving a mixture of off-site and on-site wastewater reclamation systems. It is estimated that approximately 300 decentralised wastewater reclamation systems are in operation, producing 50,000 – 60,000 m3 / day of second quality water that is used for toilet flushing, landscape irrigation, street cleaning, car washing, etc. The objective of the research described in this paper was to analyze the adoption and technical performance of these systems based on a number of case studies.

Keywords: decentralized wastewater reclamation, water-scarcity, Beijing, China

1 Introduction

Beijing, the capital of China, is located on the northern edge of the North China Plain. The city covers 16,800 square kilometer and includes four urban districts, 10 suburban districts and ten counties. Beijing, like other Chinese cities, has a rapidly increasing population. In 1970 the population counted 8.1 million people, which increased to 14.6 million by the end of 2003 (Bureau of Statistic of Beijing Municipality, 2004). It is expected that the city will count 17.4 million citizens by 2020.

Beijing is one of the driest cities in the world. The per capita fresh water resources are currently about 300 cubic meters per year, i.e. one-30th of the world's average. It is foreseen that the available water resources will not meet the increasing water demand in the near future, due to increasing population and decreasing groundwater resources. Sources at Tsinghua University and the Beijing Municipal Urban Planning Institute predict that the gap between water requirement and natural water supply will be 1.2- 3.0 billion m^3 per year in 2010 (Jia et al, 2005).

In order to alleviate water scarcity, the municipal government of Beijing is encouraging water users in the city to make use of decentralized wastewater re-use systems (DWRSs). In a regulation that was issued in 1987, hotels and public buildings that exceed a certain size are required to construct their own (local) wastewater reclamation systems. The treated wastewater is locally used for toilet flushing, landscape irrigation and urban river revival and road cleaning. The high number of DWRSs is unique in the world and provides valuable insights into the potential and constraints of decentralized wastewater reclamation which could be of use for other water-stressed cities.

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Although the regulation requiring the establishment of decentralized wastewater reclamation systems is in force now for almost 20 years, detailed information on the adoption and technical performance of these systems is lacking (Water Saving Office of the Beijing Water Authority, 2006). The objective of the research described in this paper was therefore to analyze the adoption and technical performance of these systems based on a number of case studies. The results described in this paper are part of a larger research that is in progress. The cases were analyzed by:

- Investigating the technologies that were used and their performance (technical, financial, operation & maintenance, effluent quality).
- Assessing the drivers and barriers of the stakeholders that were responsible for implementation of the decentralized wastewater reuse systems.

The paper starts by describing the regulatory framework and than describes the methods that we used for the investigation. Subsequently it provides the results and conclusions.

2 Wastewater reclamation in Beijing

2.1 Measures for alleviating water scarcity

In order to alleviate the water scarcity, the Beijing Municipal government has taken various measures (Wei, 2005). Reducing consumption through water saving has a high priority. A savings of 410 million cubic meters is planned for 2010. The Beijing Water Authority makes use of communication campaigns to make the general public aware of the water scarcity and to encourage the implementation of water-saving devices. An increase in the price of water functions as an economic lever to encourage water saving and to encourage the use of recycled water. Also water-saving and water recycling in the industry and in agriculture is receiving much notice.

A measure that gets much international attention is the south-to-north water diversion project that will transport water from the Yangtze River Valleys to the North China Plain. The south-to-north water diversion project will have three water diversion routes, namely the east route, middle route and west route. The middle route transport channel will bridge 1267 km from Danjiangkou to Beijing and will transport 1.2 billion cubic meters annually to the city transport water totals. This channel is planned to be ready in 2007.

A third important point of focus is the exploitation of non-traditional water resources (rain water, wastewater recycling). Various measures are taken to take advantage of flooding and to harvest rainfall, such as the construction of flood detention reservoirs to reduce flood peaks and replenish groundwater supplies and the establishment of small ponds to retain water for local use. Rain water harvesting should provide an additional 150 million cubic meters by 2010.

The recycling (reclamation) of wastewater receives a lot of attention, both at municipal level (Beijing Municipal government) as well as at national level (Ministry of Construction). The areas of recycling are industrial reuse, agricultural irrigation, scenic water reuse and municipal reuse (Jia et al, 2005; Wei, 2005). Municipal reuse includes toilet flushing, landscape irrigation, road cleaning, car washing, fire fighting and the use of water for construction (Ministry of Construction, 2002). According to the environment protection planning of Beijing approved by the state environment protection agency (EPA), 14 wastewater treatment plants with a total capacity of 1.2 billion cubic metres per year are planned for the urban area of the city (Wei, 2005; Wang et al., 2005). Over 20 treatment plant will be built in rural counties and satellite towns. By 2008 90% of the sewage of Beijing is treated before discharge or reuse. There will be 640 million cubic meters of water recycled in 2010.

2.2 Wastewater reuse planning

In order to facilitate wastewater reuse, the Beijing Municipal government is locating the treatment works according to their suitability and feasibility for recycling, as is illustrated in Figure 1. The city has set up special pipelines for transporting second quality water from these wastewater treatment plants to the various urban locations. Residential areas that are located in these areas should make use of the reclaimed water transported by the pipe networks.

The construction of pipelines to transport is a costly matter and is especially difficult in existing locations (Water Saving Office 2005, 2006). It is therefore that in large parts of the city, construction companies are required to recycling facilities at residential level. Also large-scale industries and enterprises, hotels, colleges and universities and office buildings are encouraged to set up small reclamation facilities. The Beijing Water Authority (BWA) also makes use of trucks to supply water to e.g. car washing companies that are not connected with the second quality water supply lines. So far, according to interviews with officials of the water saving office of BWA, there are more than 200 car washing companies using second quality water as their main water resource.

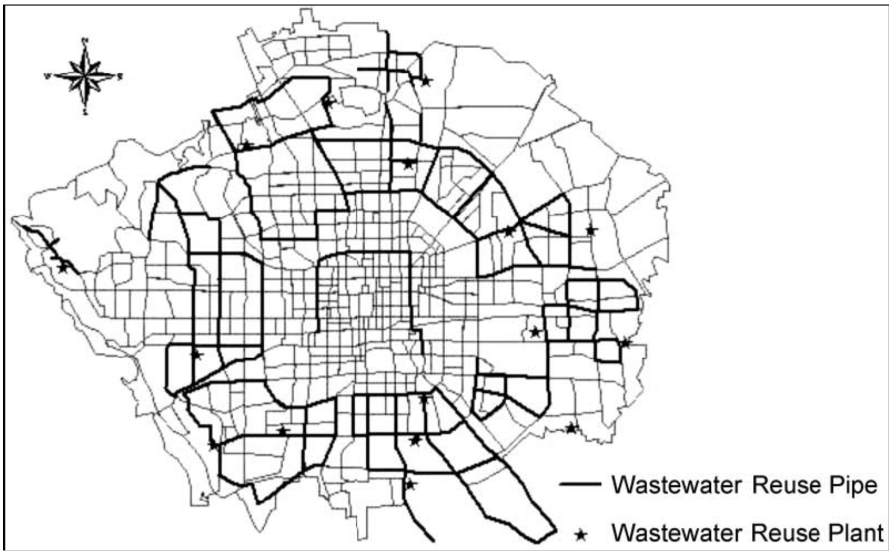

Figure 1. Wastewater reuse planning for the Beijing central region (source: Jia et al., 2005)

2.3 Decentralized wastewater reclamation facilities

In 1987, the Beijing Municipal Government issued the 'Management regulation on the construction of wastewater reclamation facilities in Beijing (trial)'. According to this regulation, hotels with construction areas exceeding 20,000 m^2 and all other public buildings with construction areas exceeding 30,000 m^2 should construct their own wastewater reclamation facilities. Also new residential areas were encouraged to implement wastewater reuse. This last category was detailed in 2001 through a regulation that residential communities required exceeding 50,000 m^2 to build a reclamation facility.

Since 1987, various additional regulations have been enacted at both municipal and national level, encouraging and requiring wastewater reclamation in urban areas. In 2002, the General Administration of Quality Supervision, Inspection and Quarantine published water quality standards for Urban Reuse of recycling water. The reclaimed water quality should comply with the standards given in the following table:

Table 1. Reclaimed water quality standards (source: General Administration of Quality Supervision, Inspection and Quarantine, 2002)

No.	Parameter	Toilet flushing	Road cleaning Fire-fighting	Urban afforestation / landscape irrigation	Car washing	Construction
1	Color ≤	30				
2	pH	6-9				
3	Odor	No unpleasant smell				
3	Turbidity(NTU) ≤	5	10	10	5	20
4	Dissolved Solids (mg/l) ≤	1500	1500	1000	1000	---
5	BOD_5 (mg/l) ≤	10	15	20	10	15
6	Ammonia nitrogen (mg/l) ≤	10	10	20	10	20
7	Anion surfactants (mg/l) ≤	1.0	1.0	1.0	0.5	1.0
8	Fe (mg/l) ≤	0.3	---	---	0.3	---
9	Mn (mg/l) ≤	0.1	---	---	0.1	---
10	Dissolved Oxygen (mg/l)>	1				
11	Free residual chloride (mg/l)	≥ 1.0 after 30 minutes contact ≥ 0.2 at the end of pipes				
12	Coliform Number/L ≤	3				

According to Jia et al. (2005) up to 2002, more than 154 DWRSs had been built in the Beijing central region of which approximately 120 were in operation (Jia et al., 2005). The Water Saving Office of the BWA estimates that at present (2006) approximately 300 DWRSs are in operation and that another 100 are under construction, spread over the city on various scales and with different technologies. According to their estimatons these systems are producing 50,000 - 60,000 cubic meters of second quality water per day or 18 – 22 million cubic meters per year. In 2005 the gross amount of recycled water used by agriculture, industry, community and administration was estimated at 200 million cubic meters per year (WSO, 2005), which indicates that the share of the reused wastewater from the on-site facilities is approximately 10% of the total.

2.4 Involved institutional stakeholders

The main institution responsible for the implementation and control of the DWRSs is the Water Saving Office (WSO) which falls under the BWA (Beijing Water Authority). The WSO is responsible for communicating the policies and regulations regarding wastewater reclamation to the relevant stakeholders and the general public. During the development and design phases of construction projects the WSO has an advisory role on the reuse concept and the reclamation technologies and has to approve of the system. After implementation the WSO will test the correct installation of the system. During this phase WSO will usually send an effluent sample to the Environmental Protection Agency to test whether the quality of the water complies with standards.

Since 2005, there is also involvement of the Spatial Planning Committee of Beijing (SPCB) and the Construction Committee of Beijing (CCB). According to new regulations that were established in 2005, wastewater reclamation projects must be approved of by the SPCB before they are built. The

CCB is responsible for construction projects in general of which the establishment of a DWRS is a (minor) part.

It is worthwhile mentioning that there is formal monitoring of the water quality of after the systems have been established. The EPA of Beijing offers services to measure the water quality on a voluntary basis. However, no records are kept of these measurements.

3 Methods

So far, information on 8 DWRSs was collected. The investigated cases were more or less randomly selected, based on our current knowledge and network of contacts. The total installed capacity of these 8 cases was 12,080 m^3/day while the actual treatment was approximately 5,500 m^3/day (it is noteworthy that these figures indicate that the WSO-estimations on the daily water production by DWRSs might be too low). Data were collected by interviewing the stakeholders related to the various DWRSs. Standardized interviews were made with the system owners, the system operators and the users of the reclaimed water.

4 Results

4.1 The investigated cases

This paper will use information of the five cases shown in Table as illustrative examples. The Table includes two universities and one hotel (Beijing Jiaotong University, Beijing Normal University and Xin Bei Wei hotel). All the universities in Beijing (12 in total) and most of the larger hotels have their own wastewater reclamation facilities, following the regulations of 1987. Bobo Garden House and Beiluchun are both examples of residential areas with reclamation facilities.

The approach and techniques implemented at the DWRSs are quite diverse. Two of the shown examples only treat grey water, while the other three treat the total flow of domestic water (grey and black water). Various treatment techniques are used, such as activated sludge, contact oxidation (a type of moving bed reactor) and an aerated ceramic filter (a fixed biofilm process). Jia et al. (2005) found a high variety in approaches. In 2002 they analysed 21 systems for grey water treatment and 12 systems for combined treatment of black and grey wastewater. They found that almost all grey water treatment systems used a contact oxidation system combined with physical and chemical treatment. For treatment of mixed wastewater several kinds of techniques were adopted, including contact oxidation plus physical and chemical treatment and SBR plus physical and chemical treatment.

The final use of the treated water is varying, although toilet flushing and landscape irrigation are dominating. It is remarkable that none of the systems is used at full capacity, which is probably due to the (legal) limitations in the reuse purposes.

Table 2 The five DWRSs that will be discussed in this article

Item	Beijing Jiaotong University	Beiluchun	Beijing Normal University	Xin Bei Wei Hotel	BOBO Garden House
Location type	University	Residential	University	Hotel	Residential
Established in	1993	1999	2001	2002	2003
Influent source	Grey wastewater	Mixed wastewater	Mixed wastewater	Grey wastewater	Mixed wastewater
Main treatment technology	Activated sludge	Aerated Ceramic Filter	Activated sludge	Contact oxidation + disinfection	Contact oxidation + Activated sludge
Maximal reclamation capacity (m^3/day)	200	640	720	120	1,200
Average reclamation (m^3/day)	150	600	400	80	300[1]
Use purposes for the reclaimed water (% of total)					
- toilet flushing	0%	yes[2]	80%	100%	80%
- landscape irrigation	100%	yes	20%	0%	15%
-street cleaning	0%	no	0%	0%	5%
- car washing	0%	yes	0%	0%	0%
- fire water storage	0%	yes	0%	0%	0%

[1] Another 700 m^3 per day are treated and than discharged to the sewer system
[2] Exact distributions not asked for

4.2 Technical performance

Table 3 shows some indicators of the technical performance of the five systems. As mentioned earlier, there is no formal monitoring of the effluent quality of the systems after they have been established. However, the EPA of Beijing offers services to measure the quality on a voluntary basis, although no records are kept of these measurements. All the investigated cases made use of the possibility with a monitoring frequency of approximately once per year. According to data that were provided by system owners all systems complied with the quality standards of Table 1. The table also shows the electricity consumption (0.7 tot 1.5 kWh per m^3) and the time input for operation and maintenance.

To investigate the robustness (defined here as chance and frequency of system failure) the reasons for potential system failure were investigated. All the operators except for the one at Xin Bei Wei hotel indicated that power cuts could lead to failure, some also reported pump malfunction as a potential reason. At the hotel a generator is installed that produces electricity. In the last three cases we also specifically asked for the number of system failures. None of the operators reported failures.

Here, it is worth to mention that the performance of the DWRSs is sometimes questioned by the Beijing Municipal government. E.g., Jia et al. (2005) refer to reports that state that small facilities show insufficient operation because of overloading due to peak flows and lack of skilled operating technicians. However, no reports on this were found so far by the authors of this paper.

Table 3 Technical performance and system robustness of the five DWRSs

Question	Beijing Jiaotong University	Beiluchun	Beijing Normal University	Xin Bei Wei Hotel	BOBO Garden House
Is the system being monitored?	yes	yes	yes	yes	yes
Compliance with effluent quality standards?	yes	yes	yes	yes	yes
Electricity consumption (kWh/m^3)?	0.75	0.72	1.00	1.50	1.20
Time input (labour) for operation and maintenance (h / year)	n.a.f.*	n.a.f.*	Approx. 8760	Approx. 1825	Approx. 1095
What could be the reason causing a failure of the DWRS?	Power cut	Power cut	Power cut / pump mal-function	pump mal-function **	Power cut
Any reported failures of the system?	n.a.f.*	n.a.f.*	0	0	0

* n.a.f. – not asked for, in the first interviews we did not include this question
** Back-up generator for electricity supply available

4.3 Financial performance

Table 4 shows the financial performance of the five DWRSs. Based on the investment costs, the costs for operation and maintenance and the current tap water price, the pay back time of the systems were calculated. The financial information was provided by the system owners and / or the companies that installed the systems. It is worth mentioning that BWA charges a different in tap water prices for public parties (i.e. 3.7 RMB/m^3 for residents and public offices) and parties from the private sector (i.e. 6.1 RMB/m^3 e.g. hotels). The investment costs only refer to the costs of the DWRS and not to the additional pipelines in the areas and / or buildings that are needed to transport the treated water to the locations of use.

The data that were found in our investigation were compared to the financial information on DWRSs of Jia et al. (2005). It showed that the investment and O&M costs of the cases that were constructed between 2001 and 2003 showed good resemblance financial results of their research. The other two cases (Beijing Jiatong U. and Beiluchun residential area) had relatively low investment costs which probably indicate that the prices of reclamation systems have increased significantly in the past 5-10 years. If we consider the information on the cases that were constructed after 2001 reliable, pay-back times of 8 to 14 years were found for the public stakeholders and 4 to 6.3 years for the parties from the private sector.

Table 4 Financial performance of the five cases

Item	Beijing Jiaotong University	Beiluchun	Beijing Normal University	Xin Bei Wei Hotel	BOBO Garden House
Established in	1993	1999	2001	2002	2003
Investment costs for the treatment system (RMB)	300,000	1,400,000	3,400,000	600,000	3,000,000
Operation and maintenance costs (including labor costs) (RMB/m^3)	0.75	1.08	1.50	1.13	1.72
Current price of the tap water (RMB/m3)	3.7	3.7	3.7	6.1	3.7
Pay back time (years)	1.9	2.4	10.6*	4.1**	13.8*

* pay back times of 5.1 and 6.3 years at a tap water price of 6.1 RMB / m^3
** pay back time of 8.0 years at a tap water price of 3.7 RMB /m^3

4.4 Drivers and barriers

This section discusses the drivers and barriers to implement DWRSs. For this purpose we interviewed the system owners of the DWRSs which were the responsible departments at the 2 universities and the manager of the hotel. The ownership (and operation) of the systems at the residential areas (Beiluchun, BOBO Garden House) lies with the real estate companies.

In all cases the drivers to implement the DWRSs were mainly financial. The incentive of the increased tap water prices is high. As already indicated in paragraph 4.3 an investment in wastewater reclamation systems is attractive because of the relatively short pay-back times. Most stakeholders also indicated that they considered the initial investment as rather high. This formed an initial barrier to them. Three of the projects received partial subsidies for the initial investment (Jiatong University, Beiluchun and Xin Bei Wei Hotel). Secondary arguments were (compliance with) the regulatory framework and awareness on the water-scarcity. The regulatory argument was a driver for most cases, however because of the absence of real penalties from the side of the BWA, not as the deciding one. Also raising water-awareness and sustainable living were arguments for all the cases. The universities also consider the DWRSs as a tool to educate students on water issues and had faculties and students design and monitor the facilities. The real estate companies of Beiluchun and BOBO used the facilities in their commercials to sell the houses.

A barrier that was put forward by the real estate companies of Beiluchun and BOBO was the uncertainty about the fees they could raise for the second quality water and the current lack of a policy from the BWA on this. Other barriers that were mentioned were the difficulty of constructing extra pipelines in existing areas for transportation of second quality water.

5 Conclusions

- Various techniques are in use for decentralized wastewater reclamation (contact oxidation, activated sludge systems, SBR systems). According to our assessment the investigated systems function well without any processing, safety and health problem. However, effluent monitoring is done on voluntary basis and real quality control by an independent party is lacking.
- There is a strong financial driver to implement DWRSs, because of the relatively short pay back times, especially for the private sector. Other drivers are related to the regulations and to awareness on water scarcity issues.
- The implementation of the regulation on DWRSs by the WSO is frustrated by the absence of real penalties. In addition the monitoring of the systems is virtually absent.

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