*Journal of Environmental Sciences (China)*, Vol. 2, No. 3, pp 67–78, 1990 ISSN 1001-0742

# Water shortage and wastewater reuse

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(Received February 19, 1990)

**Abstract**—China is not abundantly supplied with freshwater. Water shortage is a crucial problem in northern China, and affects the development of economy and causes a host of environmental and ecological problems. Water saving, water resource protection, strengthening of management and exploitation of new water resources are some of the major measures for solving the water shortage problem. Wastewater reuse is also a feasible and practical means of alleviating the problem.

**Keywords:** wastewater reuse; water shortage; water resources.

## INTRODUCTION

Water is one of the basic needs of mankind. With the development of industry and agriculture, increase in population and raising of living standard, water consumption is ever increasing. Now water shortage has become a serious problem in China. In many areas, water shortage problem inhibited and are inhibiting economic development, and caused a lot of environmental and ecological problems. On one hand more water supply is required and on the other a great quantity of wastewater is discharged into the environment, polluting both surface and groundwater on its way, making limited water resources even less. So seeking ways to make wastewater reusable is a strategical task both for environment protection and solution of water shortage problem.

## WATER RESOURCE IN CHINA

China is not abundantly supplied with freshwater. The annual water resupply is about $2800\times10^9 m^3$, which ranks sixth in the world. Among this amount, only $1100\times10^9 m^3$ is available for usage. However water resupply per capita is only $2630 m^3/a$, which is a quarter of the world average, ranges 88th in the world. Table 1 shows water resources of some countries in the world. Comparing the average water resource in China with the countries which are rich in water resource, the water resource for each Chinese is only equal to 1/50 of Canadians, 1/7 of soviets, 1/5 of Americans and 3/4 of the Japanese.

The distribution of water resources differs from region to region, and from season to season. Fig. 1 shows a map of China with the waterways. The rainfall decreases gradually from the

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sourth-east to the north-west, from about 2000mm/a to 200mm/a, even less than 50mm/a in some areas. More than 45% of the country land has an annual rainfall less than 400mm/a. The variance in rainfall with seasons is great. 70-80% of the total annual rainfall concentrates in June to September, and very often falls as rainstorms, which cause flood or rapidly flow into the sea. This water can not be used effectively. This kind of rainfall makes distribution of water resources very unbalanced in the whole country. On the south of Yangtze River, there is more than 80% of total water resource with about 38% of cultivated land, but in the basins of Yellow River, Huaihe, Haihe and Liaohe Rviers there are only 9% of the total water resources with more than 42% of the cultivated land (Table 2). The average water resource per capita in this area is only 1/9 of the country average.


**Fig.1** The water system of China

1. Songhua River
2. Liaohe River
3. Haihe River
4. Yellow River
5. Huaihe River
6. Yangtze River
7. Pearl River
8. Dontin Lake
9. Boyang Lake
10. Chaohu Lake
11. Bohai Bay
12. Dalian Bay
13. Jinzhou Bay
14. Yantai Bay

**Table 1** Water Resource in China and in some other countries

| Nation | Total amount of water resource, $m^3/a \times 10^9$ | Water resource per capita, $m^3/a \times 10^3$ |
|---|---|---|
| China | 2800 | 2.63 |
| Canada | 3122 | 121.39 |
| Brazil | 5190 | 38.28 |
| Sweden | 183 | 22.21 |
| Russia | 4714 | 16.19 |
| America | 2478 | 10.43 |
| India | 1850 | 2.43 |
| South Africa | 50 | 1.54 |
| Egypt | 56 | 1.20 |

**Table 2** Distribution of water resources in China

| Region | Area, $km^2$ | Annual total rainfall, $m^3/a \times 10^9$ | Water resource Amount, $m^3/a \times 10^9$ | Total, % |
|---|---|---|---|---|
| Heilongjiang Basin | 903418 | 447.6 | 135.2 | 4.81 |
| Liaohe Basin | 345027 | 190.1 | 57.7 | 2.05 |
| Haihe & Luanhe Basin | 318161 | 178.1 | 42.1 | 1.50 |
| Yellow River Basin | 794712 | 369.1 | 74.4 | 2.65 |
| Huaihe Basin | 329211 | 283.0 | 96.1 | 3.42 |
| Yangtze River Basin | 1808500 | 1936.0 | 961.3 | 34.18 |
| Pearl River Basin | 580641 | 896.7 | 470.8 | 16.74 |
| Rivers in Zhejiang Fujian & Taiwan Provinces | 239803 | 421.6 | 259.2 | 9.22 |
| Rivers in south-west China | 851406 | 934.6 | 585.3 | 20.8 |
| Rivers in inland regions | 3374443 | 532.1 | 130.3 | 4.63 |
| Total | 9545322 | 6188.9 | 2812.4 | 100.00 |

In regions deficient of surface water, groundwater is an important water resource. The exploitation of ground water in China has reached an up limit even over pumping.

## WATER SHORTAGE PROBLEM

Water Shortage in northern China has become acute since 1970s. As the climate became dry and rainfall decreased in the last two decades, more water was withdrawn by factories, farmers and cities. Water storage of lakes and reservoirs and runoff of rivers decreased sharply. The volume of water going to sea decreased year by year. For example, the water of Haihe

River going to sea was 14.4 billion $m^3/a$ in 1950s, it decreased to 8.2 billion in 1960s and 4.5 billion in 1970s, and became only 0.368 billion $m^3/a$ in the early 1980s. It is only 1/40 of that in 1950s. Water storage of two reservoirs, Guanting Reservoir in the south-west and Miyun Reservoir in the north-east of Beijing, major water supply sources of Beijing city, decreased sharply year after year (Table 3a and Table 3b). As the usage of surface water resource reached the up limit, groundwater usage is increasing, and overpumping of groundwater has become a serious problem since late 1970s. Capacity of groundwater supply is decreasing in many areas. There are more than 5% of the 500 thousand wells in Hebei Province depleted their water supply each year, and 40% of the wells yield only half their original supply capacity. In another example, a large petrochemical plant which located in the south-west of Beijing, groundwater supply decreased 50% from 1980 to 1986 (Table 4). This industrial enterprise is short of 2-3 million $m^3$ of water supply each year. How to meet the water demand for further development of production is a serious problem.

**Table 3a** The average of entrance water of Guanting Reservoir

$m^3/a \times 10^9$

| Year | 50s | 60s | 70s | 1985 |
|---|---|---|---|---|
| Water volume | 1.6 | 1.3 | 0.6 | 0.426 |

**Table 3b** The average volume of water storage of Miyun Reservoir

$m^3/a \times 10^9$

| Year | Original | 80s | 1985 | 1986 |
|---|---|---|---|---|
| Water Volume | 4.0 | 2.6 | 1.0 | 0.65 |

**Table 4** The decrease of groundwater supply in an industrial area in the south-west of Beijing

| Year | Water supply, $m^3/a \times 10^6$ | Decrease rate, % |
|---|---|---|
| Original | 56.76 | 0 |
| 1980 | 50.46 | 11.0 |
| 1981 | 40.22 | 29.1 |
| 1982 | 33.62 | 40.8 |
| 1983 | 34.09 | 39.9 |
| 1984 | 25.28 | 55.5 |
| 1985 | 21.83 | 61.5 |

While water resource is limited, water demand increases continually as industry, agriculture and population growth. The contradiction between water demand and water supply is acute. Table 5 shows the water demand in China in 1980 and the anticipated demand by the year 2000. As metioned above, the total water supply in China is 2800 billion $m^3/a$, among this, only 1100 billion $m^3$ is available for use. It means, the demanded water will be over 60% of the available water resource. These are the country average; in northern China, the situation is

even worse. Water demand over available water supply will be a popular problem. For example, in Beijing, there will be a big negative gap between water demand and water supply by the year 1990, and about 1/3 of the water demand will not be met by the regional water resource (Table 6). An investigation in 1986 indicated that more than 200 cities in the whole country had water shortage problems, and those in 40 cities were very serious. Economic losses is about 20 billion RMB yuan in 1986 as a result of water shortage. The northern China plain is one of the most important region of crop and cotton production in China, but the agricultural production increases slowly in the past three decades, the most basic reason is water shortage. For example, the crop production is only 2250 kilogram per hectare in Cangzhou Prefecture, which is about 100km away from the south of Tianjin. The neighboring prefecture has very similar geographical condition with Cangzhou, but the crop production in this area is 7500kg per hectare, three times higher than that of Cangzhou. The only difference is that water shortage is a long-time problem in Cangzhou, and much better in the neighboring prefecture. The area of irrigation of cultivated land decreased almost 70 thousand hectare from 1980 to 1986 because of water shortage. It is quite clear that water shortage has become an inhibition factor for economic development.

**Table 5** Water demand in 1980 and predicated demand by year 2000 in China

| | | $m^3/a \times 10^9$ |
|---|---|---|
| Item | 1980 | 2000 |
| Total amount | 474.7 | 647.8 |
| Agricultural usage | 417.5 | 514.7 |
| Irrigation | 400.1 | 480.0 |
| Domestic | 8.0 | 13.4 |
| Animals | 5.7 | 8.3 |
| Others | 3.7 | 13.0 |
| Industrial usage | 52.3 | 109.1 |
| Steam electric plants | 2.6 | 73.1 |
| Other industries | 49.7 | 36.0 |
| Municipalities | 4.9 | 24.0 |
| Total water resource in China | 2800 | |
| Water resource available for use | 1100 | |

**Table 6** The Gap of water supply and demand in Beijing

$m^3/a \times 10^6$

| Year | Item | Frequancy, 50% | 75% | 95% |
|---|---|---|---|---|
| 1984 | Supply | | | 400.5 |
| | Demand | | | 377.8 |
| | Gap | | | +22.7 |
| 1990 | Supply | 422.0 | 374.0 | 338.0 |
| | Demand | 494.6 | 546.4 | 546.4 |
| | Gap | 72.6 | -172.4 | -208.4 |
| 2000 | Supply | 431.0 | 369.0 | 334.0 |
| | Demand | 634.2 | 674.8 | 674.8 |
| | Gap | -221.2 | -305.8 | -348.0 |

*Water pollution aggravates water shortage problem*

With the industrial development since 1970s water pollution has become ever more serious. Now it is one of the major environmental problems in China. The volume of wastewater discharged is increasing by the year and has reached 36.8 billion $m^3$ in 1988 (Table 7). Wastewater treatment techniques and facilities have lagged far behind the growth of industrial production and city construction. Nearly 80% of wastewater was discharged into the environment directly without any treatment. As a result, rivers, lakes and groundwater have been polluted. A survey of 878 rivers in the early of 1980s indicated that 82% of them were polluted to some degree. More than 5% of total river length had become fishless, over 20 waterways became unusable for agricultural irrigation due to pollution.

**Table 7** Wastewater quantities and percentages treated in recent years and predicted by the year 2000

| Year | Quantities, $m^3/a \times 10^9$ | | | Wastewater percentage, % | | Percentage treated, % | |
|---|---|---|---|---|---|---|---|
| | Industrial | Domestic | Total | Industrial | Domestic | Industrial | Domestic |
| 1980 | 22.54 | 7.54 | 30.16 | 75 | 25 | | |
| 1981 | 23.79 | 6.36 | 30.27 | 79 | 21 | | |
| 1982 | 23.94 | 7.13 | 31.00 | 77 | 23 | | |
| 1983 | 23.88 | 7.11 | 30.93 | 77 | 23 | | |
| 1984 | 25.13 | 7.16 | 32.39 | 78 | 22 | | |
| 1985 | 25.74 | 8.54 | 34.15 | 75 | 25 | 22 | 2.43 |
| 1988 | | | 36.80 | 75 | 25 | 20 | |
| 2000* | 56.10 | 21.70 | 77.60 | 72 | 28 | 70 | 30 |

* Predicted

Lakes surrounding cities have become receivers of large quantities of urban sewage and industrial discharge. Many lakes are losing their functions of drinking-water supply, aquatic production and recreation.

Groundwater was polluted because of the random discharge of untreated industrial waste water. Heavy metals, phenols, organic chemicals and some kind of bacteria have been found in groundwater. Wells have to be closed because pollution levels has not met the standards for

drinking-water quality.

Water pollution makes the limited fresh water resource even less, and aggravates water shortage problem.

*Environmental and ecological problems caused by water shortage*

The ratio of wastewater to runoff of rivers is increasing in northern China because the runoff of rivers have decreased rapidly in the last two decades. Table 8 shows the ratio of wastewater to runoff in some major rivers in China. The ratio is over 0.2 for Yellow River, Haihe River and Liaohe River. The water quality of these rivers is getting worse because there have not enough fresh water to dilute the wastewater.

**Table 8** The ratio of wastewater to runoff for some rivers in China

| River | 1980 | | | 1990 | | | 2000 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 90% | 75% | 50% | 90% | 75% | 50% | 90% | 75% | 50% |
| Songhua River | 0.212 | 0.035 | 0.025 | 0.295 | 0.058 | 0.041 | 0.399 | 0.102 | 0.069 |
| Liaohe River | 0.320 | 0.204 | 0.144 | 0.388 | 0.361 | 0.254 | 0.802 | 0.661 | 0.466 |
| Haihe River | 0.239 | 0.156 | 0.116 | 0.273 | 0.183 | 0.137 | 0.197 | 0.151 | 0.123 |
| Yellow River | 0.224 | 0.049 | 0.040 | 0.365 | 0.099 | 0.078 | 0.502 | 0.195 | 0.140 |
| Huaihe River | 0.081 | 0.045 | 0.031 | 0.085 | 0.059 | 0.049 | 0.183 | 0.112 | 0.090 |
| Yangtze River | 0.044 | 0.012 | 0.011 | 0.064 | 0.018 | 0.016 | 0.126 | 0.036 | 0.032 |
| Pearl River | 0.016 | 0.007 | 0.006 | 0.033 | 0.014 | 0.012 | 0.056 | 0.028 | 0.024 |

note: 90%, 75%, 50% in the table means that the ratio appeared or will appear in that frequency.

Pollution is diffused owning to the use of large quantities of wastewater. For example, 32.2% of the total cultivated land of Tianjin suburbs is utilizing city sewage as irrigation, because of the short of fresh water. Cases of damage of crop seedlings, animals' injuries and deaths due to water pollution have been reported. Crops and aquatic products are polluted by hazardous chemicals from irrigation of wastewater and become inedible. Investigations has shown that economic losses of our country in 1986 due to water pollution were close to 30 billion RMB yuan.

Because of over-pumping of groundwater, water table drops rapidly, funnel expands successively, land subsidence and sea water infiltration become serious.

Water table dropping was fast in northern China, for example, the average dropping of water table in Beijing was 0.5–1m/a since 1960. The accumulated water table dropping from 1972 to 1980 in Tianjing was 47.5m, averaging 5.3m/a (Table 9). The funnel area is expanding, land subsidence caused, and the speed of subsidence increasing year after year. For example,

the average subsidence each year in 1960s was 2–5mm, it became 10mm in 1970s, and from 1980 was 81mm.

Soil is desertified and salinized, and vegetation decayed. The desertified area amounts to 34.9% of the total land in six counties surrounding Beijing, and 1/6 of the total land is in the process of desertification. There are large areas around the coast in Shandong province salinized.

River mouth was silted up because the amount of river water into the sea reduced sharply, which affects the reproduction of the migratory fishes.

**Table 9** Water table dropping and land subsidence in Beijing and Tianjin areas

| | Beijing | | Tianjin | |
|---|---|---|---|---|
| Water table dropping | 25–32m | 1–2m/a | 47.5m | 5.3m/a |
| Funnel area | 1000km$^2$ | | 521km$^2$ | |
| Land subsidence | | 2–5mm/a (1960 1970) 10mm/a (1970–1980) 81mm/a from 1980 | 2.3m (1959–1984) accumulated | |

These environmental and ecological problems caused by water shortage seriously affect industrial and agricultural production and humanlife.

*Measures for solving water shortage problem*

Water saving, water resource protection, strengthening of management and exploitation of new water resource are the major measures for solving the water shortage problem.

1. Water saving

Water saving is a most economical and effective measure to improve the situation of water demand and water supply. In China there is a big potential for water saving in agriculture, industries and domestic usage.

Agriculture is the largest user of water. Irrigation techniques are underdeveloped in most parts of China. At present the usage efficiency of water is quite low. Improving irrigation technology, for example, using sprinkling and dripping irrigation, will save water 30–50%. Canal with lining can protect water from seepage loss and save water by 20%. Pipe water transfer instead of canal could protect water from evaporation and seepage loss, and save water about 20–30%. Water saving in industries also has great potentiality. Water use in industrial production is quite high compared with that in developed countries. For example, in some major industries, such as steel, oil and pulp industries, water use in China is 10 to 30 times higher than that in developed countries (Table 10). Water recycling rate in many factories is quite low. It can be improved by improving management and production processing. Table 11 shows the effect of water saving in industries in Beijing and Tianjin. Water saving in industries has big potentiality

and a lot of things can be done. Policy of water quota encourages factories to save water.

**Table 10** Water consumption for per ton products
unit: $m^3$

| Industrial | In China | In developed countries |
|---|---|---|
| Steel | 60–70 | 5–10 |
| Oil | 2–32 | 0.3–1.2 |
| Pulp & paper | 270–1000 | 30 |

**Table 11** Examples of water saving in industries

| | Beijing | Tianjin | Some other cities |
|---|---|---|---|
| Water recycling rate | 70% | 63.4% | <50% |
| Output value increasing | 32.3% (1980–1984) | 63.4% (1979–1985) | |
| Water consumption decreasing | 32.3% (1980–1984) | 20% (1979–1985) | |
| Water consumption $m^3$/per capita, $10^4$ Yuan (RMB) | 333 (1984) | 167 (1984) | 400–600 |

2. Water resource protection

First important thing for water resource protection is pollution control, including water pollution control and solid waste control. Vegetation protection is also important for water resource protection.

Good management system and good management activities are very important for solving the contradiction of water demand and water supply. There are a lot of policy and technique species. Those would not be discussed in this paper.

3. Exploitation of new water resources

Because the available fresh water resources have already been exploited, exploitation of new water resources including long distance water transfer and wastewater reuse is necessary. From a long-term point of view, water diversion from southern China to the north seems to be a basic way to solve the water shortage problem in northern China. A great project of water diversion from Yangtze River to the northern China have been planned for many years, the diversion works in the east line and the middle line have already been started in 1961 and 1969, the water transfer work had been partially done, and some benefits have been reaped. However the diversion engineering project needs huge investment, and is not to be fulfilled in the near future; it is a long-term task.

Wastewater reuse is another measure for water resource exploitation. Reuse or recycle the reclaimed wastewater after proper treatment is beneficial both for solving the water shortage problem and the environmental protection.

## WASTEWATER REUSE

Wastewater as a water resource has virtues of stable water quality and quantity, i. e. not changing with seasons, not contesting water with neighboring areas, and with no need of long-distance water transfer. In principle, all industrial and domestic wastewater can be treated to the water quality level to meet the reuse purpose. An important point to be considered is the economic feasibility. Taking account of public health and economic consideration, the following water resources and reuse purposes are practical.

Municipal sewage can be treated and reused for irrigation. It is carried out by the farmers in the areas where rainfall is not enough.

Domestic and industrial wastewater can be treated and reclaimed for non-body-contact usage such as washing toilets, watering urban vegetation and some recreation activities.

Domestic and industrial wastewater can be treated for some industrial usage purpose, such as cooling water, makeup water for recycle cooling water system, or even for some production processing usage.

Reclaimed water from wastewater can be recharged into underground to protect land from subsidence in the areas where groundwater is overpumped.

According to practice and experiences of wastewater reuse in other countries as well as the practical example and research results, there is no doubt that wastewater reuse is feasible both in technology and economic point of view. Table 12 shows some research projects and examples of wastewater reuse in China.

Investigation has been made by some experts for the comparison of cost of wastewater reuse with that of long-distance water diversion. It is evaluated that the investment for wastewater reuse is cheaper than the investment for water transfer. For example, suppose the municipal sewage would be treated and reused as industrial cooling water or other general purpose reuse (such as flush the toilet or water the vegetation), if the secondary treatment facilities have already been incorporated in the wastewater treatment plant, the investment for the facilities which is required by the reuse purpose is about equal to the cost for 10km distance water transfer. If there is no secondary treatment facilities in the treatment plant, the secondary treatment and advanced treatment facilities should be built up for the water reuse purpose, the investment would be about 30–50km distance water transfer. Considering that in some area there may not be possible to divert water within 10 to 50km distance, the cost for wastewater reuse will be acceptable. As wastewater reuse exploits new water resource and brings benefit to factories, so it is easer to apply in factories than wastewater treatment only for discharge purpose. Besides, wastewater treated and reclaimed under reuse process would decrease the quantities of wastewater to be discharged to environment. So, wastewater reuse is good both for solving water shortage problem and water pollution control.

**Table 12** Some research projects and application examples of wastewater reuse in China

| Water source | Objective of reuse | Treatment process | Investment (evaluated) yuan/$m^3$ water | Operation cost, yuan/$m^3$ water | Example |
|---|---|---|---|---|---|
| Municipal sewage | Cooling water for industrial | Sewage → secondary treatment sedimentation → aerobic → clarification → filtration | 0.05 | | Dalian (experimental) |
| Municipal sewage | Industrial use | Sewage → secondary treatment → biofiltration → ozone oxidation | 593 | 0.33 | Tai Yuan (experimental) |
| Metallurgical wastewater | Industrial use for smelting and steel rolling | Wastewater → sedimentation → air floating → filtration | 363 | 0.30 | Tai Yuan (in practice) |
| Domestic sewage | For washing toilets | Wastewater → aerobic → flocculation → filtration → disinfection | | 0.13 | Beijing (in practice) |
| Petro chemical industrial wastewater | Cooling water make-up water for cooling water recycling system | Wastewater → flocculation → bio-filtration → sandfiltration → disinfection (RO treatment) | 500 | 0.14 | Yan Shan petrochemical corporation (Beijing) (experimental) |
| Municipal sewage | Industrial use domestic use recreation use | | | | Tianjin Ji Zhuang Zi wastewater Treatment plant (Research Project) |

**Table 13** Economic comparision

| Water Source | Situation | Reuse Objective | Investment comparision |
|---|---|---|---|
| Municipal sewage | Already has secondary treatment | Cooling water in industry or for other use | Equal to the cost for 10 km water transfer |
| | If without secondary treatment | For general usage | Equal to the cost for 30km water transfer |
| | | Cooling water in industrial | Equal to the cost for 50km water transfer |

## CONCLUSION

Water shortage is becoming an acute problem in northern China. This problem is inhibiting economic development in some areas. Water waste and water pollution aggravate the contradiction between water supply and demand. Among many measures for solving water shortage, wastewater reuse is a feasible and practical way of alleviating water shortage, and is beneficial for environmental protection.

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