International Review for Environmental Strategies
Vol. 6, No. 2, pp. 269 – 290, 2006

Special Feature on Groundwater Management and Policy

Towards Sustainable Groundwater Management in Asian Cities—Lessons from Osaka

Yatsuka Kataoka[a]

Groundwater is at risk in many cities in Asia as a result of excessive abstraction. Without proper groundwater management, the precious resource will deteriorate further. In cities such as Bangkok (Thailand), Tianjin (China), and Bandung (Indonesia) groundwater problems such as dropping water tables and land subsidence have been observed, and national and local government have taken some measures to overcome the problems. The city of Osaka in Japan also experienced severe land subsidence and dropping groundwater levels from 1950 to 1960, but intensive measures to stop over-exploitation of groundwater succeeded in mitigating the problems. The key to Osaka's success is a combination of controlling groundwater abstraction and provision of surface water as an alternative water source. In the long run, however, such intensive measures created other problems in water management such as a rise of the groundwater level, which has caused damage to underground building infrastructure. The experience of Osaka tells us the importance of flexibility and a long-term perspective in policymaking and implementation.

Keywords: Groundwater, Land subsidence, Asia, Industrial water.

1. Introduction

Approximately 95 percent of all available freshwater worldwide is in the form of groundwater (Morris et al. 2003). Typically, groundwater exists ubiquitously and is easily exploited at a relatively low cost. It is less affected by droughts than surface water and basically maintains uniform quality and temperature. These characteristics make groundwater more accessible, useful, and reliable than other water sources, and people tend to depend on it for various purposes wherever it is available.

In Asian cities, groundwater has long been utilized in various aspects of human activities and played a large role in their development. In many cities, however, abstraction of groundwater has intensified to meet increased water demands, which has resulted in negative consequences such as dropping water tables, less yield from wells, land subsidence, and saltwater intrusion into groundwater supplies. These negative consequences of excessive groundwater abstraction can be observed in large cities in Asia such as Bangkok, Jakarta, Beijing, Shanghai, and Tianjin. The problems are either irreversible or are serious enough that they take a long time to restore the groundwater to its original state. They also cause socioeconomic losses such as shortages of water needed to sustain urban activities and damage to building infrastructure. In order to prevent or mitigate problems with groundwater and the associated social and economic losses, adequate groundwater management is needed, especially in urban and semi-urban areas, where population and economic activities will continue to expand in the years ahead.

a. Policy Researcher, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan.

Dating back more than 50 years, some Japanese cities have experienced similar problems with groundwater, including the city of Osaka in the western part of Japan. Faced with severe land subsidence caused by over-exploitation of groundwater during the 1950s and 1960s, Osaka undertook intensive measures to control groundwater abstraction and succeeded in halting land subsidence. This success, however, resulted in some unfavorable, long-term consequences, such as damage to underground building infrastructure caused by now-abundant groundwater. The intensive measures implemented in Osaka are also blamed for hindering more effective use of groundwater and/or rationalization of overall water use. For sustainable use of groundwater in Asian cities, which are expected to continue growing over the next decade, the lessons that can be learned from an overview of Osaka's long-term experience may provide useful information and have implications for future groundwater policymaking in other cities.

2. Groundwater management in Asian cities

2.1. Groundwater use and related problems

Groundwater has long contributed to sustaining the lives of people in Asian cities, and about one-third of Asia's population still depends on it for drinking water supply (Morris et al. 2003). As well, industries often depend on groundwater as a cheap and reliable water source for production activities. In Bangkok, for instance, large-scale groundwater abstraction began as an alternative to surface water for public water supply, and private pumping for domestic and industrial use is now dominant (AIT 2006). Tianjin has also experienced a rapid increase in groundwater use since 1948, when an estimated 40,000 cubic meters per year (m^3/yr) was exploited. By 1981, this had grown to 10.38 million m^3/yr (Mm^3/yr) (Nankai University 2006). As a result of groundwater control measures implemented since then, pumpage had decreased to 7 Mm^3/yr by 1993, but water availability in the city is still very much constrained and therefore groundwater use tends to increase in drought years. Ho Chi Minh City saw a rapid increase in groundwater use in the 1990s, and this will likely continue as the city develops and grows, mostly for domestic and industrial use. In Bandung, groundwater abstraction reached 0.45 Mm^3 per day (Mm^3/d) in 1996 at its peak (West Java EPA 2006). Eighty percent of the groundwater pumped up is for industrial purposes, and the trend in the city's groundwater use depends largely on industrial production activities. Jakarta also depends on groundwater, but mainly for drinking water in areas without public water supply. In Metro Manila, where the industrial sector depends mostly on groundwater, pumpage reached 970,000 cubic meters per day (m^3/d) in 1990 (Bumatay 2004). Calcutta, Dhaka, Beijing, and Shanghai also depend largely on groundwater (Morris et al. 2003).

Many large cities in Asia have been developed on coastal estuaries with a substratum of soft sediments, and excessive abstraction of groundwater has often resulted in environmental problems such as dropping groundwater levels, land subsidence, and saltwater intrusion. In Bangkok, the dropping water table and land subsidence became big problems in the late 1970s. The impact of land subsidence has since extended from Metropolitan Bangkok to neighboring provinces such as Pathum Thani and Samut Sakhon, where it reached 12.6 centimeters per year (cm/yr) in one area in the early 1990s. Jakarta was also suffering from land subsidence at a rate of 3–6 cm/yr in the 1980s (Morris et al. 2003). Large cities in China, such as Beijing, Shanghai, and Tianjin, have also had the same experience as Bangkok and Jakarta. Shanghai, for example, sunk by more than 10 cm/yr in the 1960s, which put the city below sea level (*China Daily* 2003).

The environmental damages caused by excessive groundwater abstraction have induced substantial social and economic losses. Due to land subsidence, for example, flood-affected areas have grown, and urban infrastructure, such as roads and buildings, has been damaged in many cities in Asia. The extension of flood damage may also increase the risk of communicable diseases in Asian cities, where sewage and drainage systems are often poor. The economic losses incurred in Shanghai from land subsidence in the last 40 years, for example, was estimated at 290 billion yuan, or US$35.1 billion (*People's Daily Online* 2003). Therefore, proper groundwater management is needed from the viewpoint of city security.

2.2. State of groundwater management

In response to dropping groundwater levels and the resultant problems of land subsidence and saltwater intrusion into groundwater supplies, some cities have introduced measures to control groundwater abstraction. Table 1 shows the major policy measures that have been introduced in Bangkok, Tianjin, and Bandung. There are three main elements of effective groundwater management, namely, (a) regulation of groundwater abstraction (including registration and permit systems), (b) provision of alternative water resources, and (c) provision of economic incentives/disincentives to reduce groundwater abstraction (e.g., groundwater user charge).

A combination of pumping regulations and provision of alternative water resources has proven to be essential for these cities to control groundwater use without negatively affecting people's lives and the city's development, but finding other sources of water and the financial resources necessary for development of new sources was not easy. For instance, the Metropolitan Water Authority, which supplies water to the Bangkok Metropolitan area, recently extended its water supply service to 90 percent of population. This has contributed to a reduction of groundwater use to some extent, but the availability of water resources in the city is still very critical. Tianjin started inter-river basin transfers of water in 1980s and is now expecting to receive water from the large South-North Water Transfer Project as a new source of water, but there is uncertainty of the environmental impacts of the project, including water quality. New water development projects are under consideration in Bandung, but conflicts between different water user groups might not be easily resolved. Once other water resources become unavailable, people are forced to depend on groundwater. In this sense, the future of groundwater demand will depend on the availability of alternative resources.

Charging for groundwater abstraction is common in the three cities, but its effectiveness in reducing pumpage is not well proven. In Bangkok, the use charge began to be imposed in 1984, but it did not result in pumpage reduction. However, a recent step-by-step but sharp increase of groundwater charges (from 3.5 baht/m^3 in 2000 to 8.5 baht/m^3 in 2003) in Bangkok and its vicinity and the introduction of an additional charging scheme, called the Groundwater Preservation Charge (8.5 baht/m^3), seem to be contributing to a reduction in groundwater pumpage (AIT 2006). On the other hand, the relatively low tariffs on groundwater in Tianjin and Bandung have failed to motivate users to stop pumping groundwater.

From the perspective of conservation of limited water resources, demand management by introducing economic instruments is the most important tool in water management, including groundwater. Current groundwater policy, however, does not fully include demand management measures, and groundwater management policy is not always well coordinated with other areas of water management.

Table 1. Groundwater management policy measures implemented in three Asian cities

	Main elements of groundwater management			
	Regulations on groundwater use	Provision of alternative water resources	Economic incentives /disincentives for reduction of groundwater use	Others
Bangkok	By national law (Groundwater Act in 1978)	Surface water by municipal water supply scheme	User charges and additional charges called a preservation charge	Licensing drilling, encouragement of conjunctive use in the industrial sector, etc.
Bandung	By provincial and municipal laws (all sectors)	Considering expansion of surface water use	Groundwater tax	
Tianjin	Local level (all sectors in urban areas)	Surface water transfer from other river basins	User charges (excluding the agricultural sector)	Encouragement of water conservation in industries

Sources: AIT 2006 (Bangkok); West Java EPA 2006 (Bandung); Nankai University 2006 (Tianjin).

The cities facing groundwater problems have already introduced groundwater management measures, but no such schemes exist in cities where groundwater problems are still not recognized by society. For example, in Ho Chi Minh City, where groundwater abstraction for different uses has been increasing, there are no specific measures in place to control groundwater use (Dan et al. 2005). In Colombo, Sri Lanka, where surface water use is dominant, there is no control of groundwater abstraction either. Considering that the nature of damage to groundwater resources is irreversible or requires long-term remediation, and that the negative impacts have various socioeconomic consequences, groundwater demand should be well managed in order to minimize and prevent any damage to the resource.

3. Groundwater management in Osaka

3.1. Background

The city of Osaka is located in the western part of Japan. It lies along the coast from north to south and is open towards Osaka Bay on the west. The Yodo River runs through the northern part of the city and has long been its main source of water. The city area measures only 221.96 square kilometers and was home to about 2.6 million people in 2002.[1] Annual precipitation ranges from 950–1,300 millimeters.

1. http://www.city.osaka.jp/english/facts_figures/economy.html.

Most of the city is on lowlands on the Osaka Plain (except for Uemachi Hill located in the city center) located on an alluvial formation with rather soft ground, consisting of cohesive soil and sandy soil. The thickness of the alluvial formation in the coastal area of the city is about 35 meters (m), which consists of layers of clay and silt (GEC 1994).

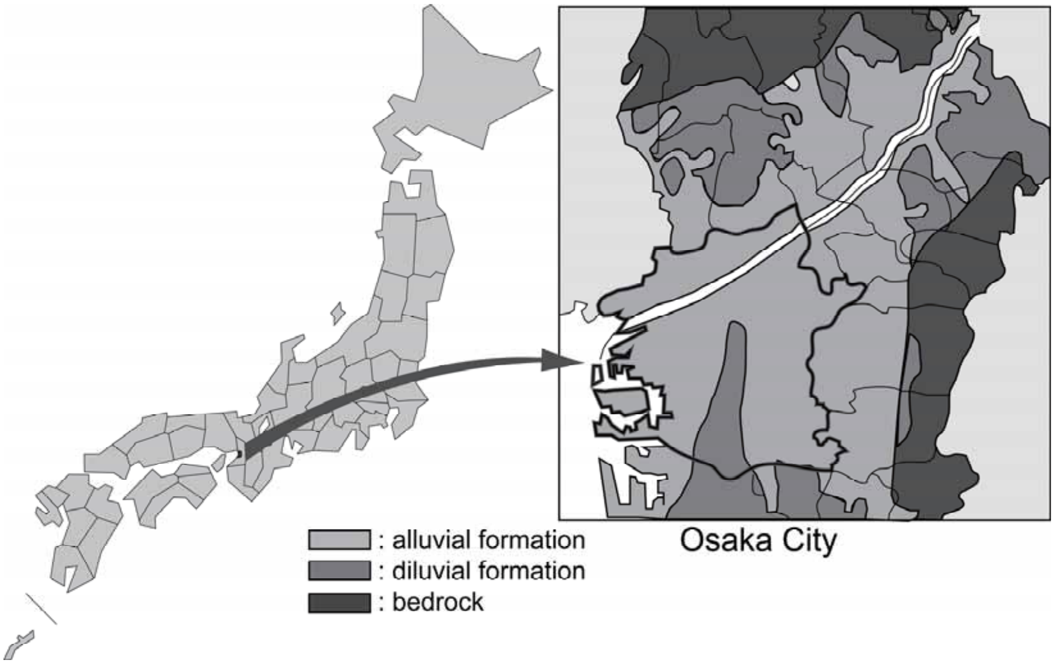

Figure 1. Location of Osaka and its geological characteristics

Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993.

Osaka has been known for centuries as the city of merchants. In the beginning of the twentieth century, there was a rapid increase in manufacturing industries and heavy industries along the coast of Osaka Bay. The city enjoyed a booming economy in the 1950s and 1960s, but it began to slow in the 1970s and its production value has decreased since 1990. Even so, Osaka's economic activity in 2003 was over $2 billion, more than the gross national product of either Hong Kong or Thailand.[2]

3.2. Water resources and groundwater use in Osaka

Historically, people in Osaka have depended on an abundant water supply from the Yodo River. A public water works was first constructed in 1885, and the coverage rate of the public water supply reached 100 percent by 1970. The volume of the annual water supply from the river in fiscal year 2002 was 495.5 Mm^3 (Osaka City Waterworks Bureau 2003).

Groundwater has played a supplementary role to surface water in the city, because it was often too salty for drinking and therefore was used for non-drinking purposes such as washing or watering plants (Osaka City Waterworks Bureau 2000). On the other hand, it played an important role in the

2. http://www.city.osaka.jp/english/facts_figures/economy.html.

development of industry in the city. Intensive industrial use of groundwater began in the early 1900s, when the city experienced a boom in industrial development. In the 1950s, in the course of the economic reconstruction period after World War II, groundwater use began to intensify again. According to a survey of 30 factories in the industrial area of the city in 1955, 65.5 percent of total freshwater use depended on groundwater (Osaka City 1957). A new trend began in the 1950s of using groundwater for cooling and flushing purposes in large buildings such as office buildings and commercial buildings (Japan Society of Civil Engineers Kansai Chapter 2002).

Total groundwater pumpage in the city was 21 Mm^3 in 1953 and reached its maximum in 1962 at about 123 Mm^3/yr, when 82 percent of abstraction was used by the industrial sector and the remaining volume by buildings. In the industrial sector, the food industry consumed the most (33 percent), followed by the paper and pulp industry (21 percent) and the chemical industry (18 percent).[3] Figure 2 shows the types of groundwater for industrial use and building use in the same year. In both beneficial use, groundwater was used most for the cooling purposes (Osaka City Comprehensive Planning Bureau 1963).

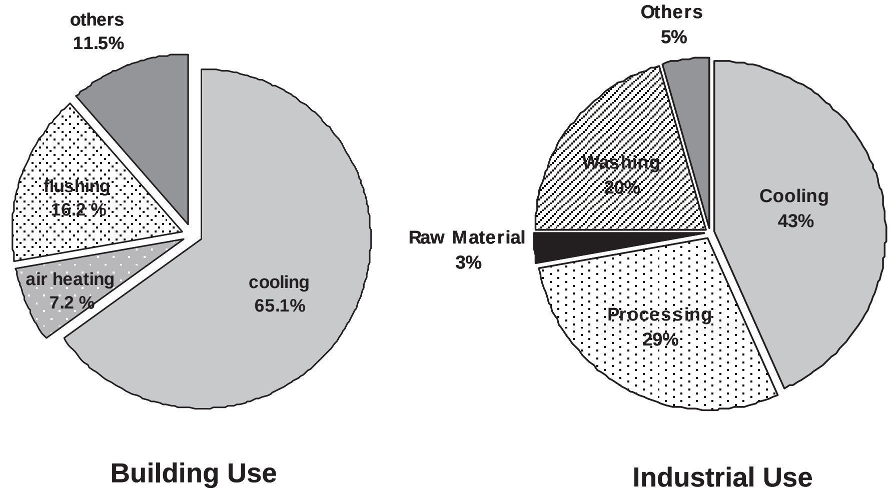

Figure 2. Groundwater use in Osaka by type of use, 1962

Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1972.

3.3. Dropping groundwater levels and land subsidence issues

Land subsidence began to be observed in the 1920s in the industrial areas of coastal Osaka, but there was a scientific debate on the cause—geological processes or over-exploitation of groundwater. Therefore, no active countermeasures were implemented to control groundwater abstraction, but the city government started regular monitoring of land subsidence and the groundwater level to obtain chronological data.

3. According to a study in 1960, conducted before strict groundwater abstraction controls were introduced in 1962, chemical industries consumed 32 percent of total groundwater abstraction, followed by food industries (22 percent) and pulp and paper industries (21 percent) (Osaka City Planning Bureau 1960).

The incidence of subsidence ceased during World War II, but in the early 1950s, at the beginning of post-war economic growth, the water table began to drop again and the city resumed sinking. The fact was acknowledged that there was a correlation between groundwater abstraction by the industrial sector and land subsidence, and the city government began to take action.

The increase in the magnitude of land subsidence resulted in various hindrances to the development of the city. As the land base sank, the height of dykes became lower and they lost their ability to protect the city from flooding. This resulted in a worsening of the negative impacts of flooding, especially during typhoons. The city had to spend about $2.5 billion (in 2000 prices) between 1955 and 1969 to reinforce dykes, raise bridges, and develop a drainage system (Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1972). Industries also had to invest in reconstruction and build their own dykes to protect themselves from flooding. Even so, damage to city infrastructure such as bridges and railway stations intensified. Such tangible evidence of the damage caused by land subsidence raised public awareness of the problem.

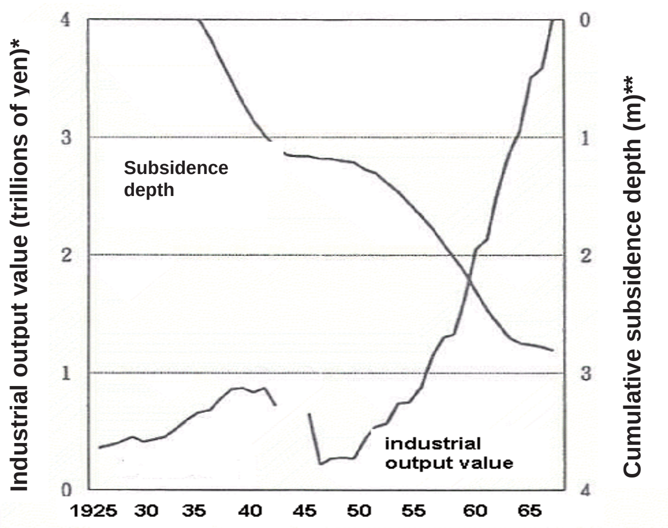

Figure 3. Land subsidence and industrial output value in Osaka

Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993.
*In 1965 prices.
**At Nishi-4 (Torishima, Konohana-ku).

3.4. Limiting groundwater abstraction to counter land subsidence

Management measures in Osaka started to work in controlling land subsidence by reducing groundwater abstraction. As figure 4 shows, there are two lines of management according to use: (1) industries and (2) buildings. The main element of groundwater control was regulations on abstraction, which were supported by provision of alternative water resources and financial and technical assistance to take the actions necessary to reduce groundwater use.

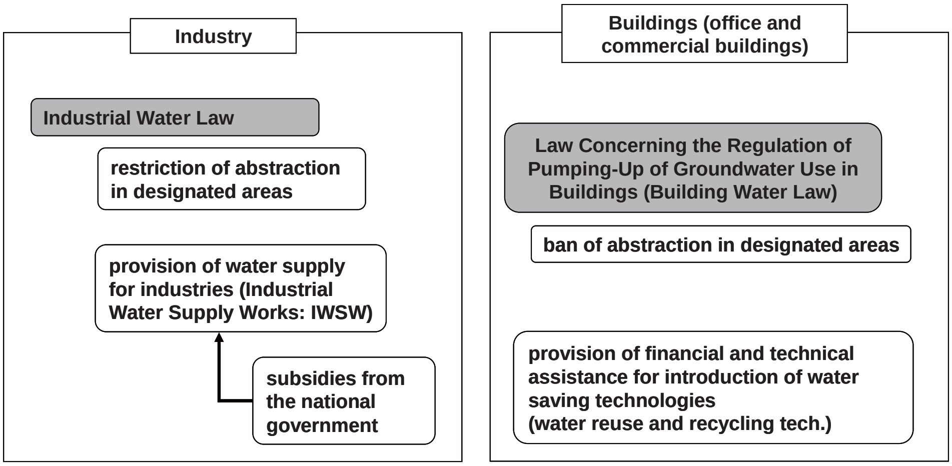

Figure 4. Outline of the types of groundwater management in Osaka

a. Regulation of groundwater abstraction

The main element of effective groundwater management is regulation of groundwater abstraction. For the industrial sector, a national law, named the Industrial Water Law, was enacted in 1956. Even so, because groundwater is regarded as an exclusive right of landowners there was hesitation to regulate groundwater abstraction at that time. In one sense the law was a breakthrough for groundwater control, but as a tool for controlling groundwater abstraction it was very weak, because it only applied to new wells, not existing ones.

Another significant feature of the law was that it had the dual purposes of industrial development and controlling land subsidence in the designated area, and it set construction of plants for industrial water supply works (IWSW), a new scheme of water supply exclusively for the industrial sector, as one of the terms of groundwater control.

Regarding groundwater abstraction for use in buildings, the Osaka city government enacted the Osaka City Land Subsidence Control Ordinance in 1959 and tried to regulate well abstraction in five wards (*ku*) under the same conditions as the Industrial Water Law. Therefore, the ordinance did not apply to existing wells either.

Consequently, both the Industrial Water Law and the ordinance failed to effectively control groundwater abstraction, and land subsidence intensified. At Kujyo Station, located in the coastal area of the western part of the city, the groundwater level was recorded at minus 24.44 m in 1957, minus 26.84 m in 1959, and minus 31.09 m in 1962 (Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1972). The area affected by land subsidence expanded to the central and eastern parts of the city and intensified as well (figure 5).

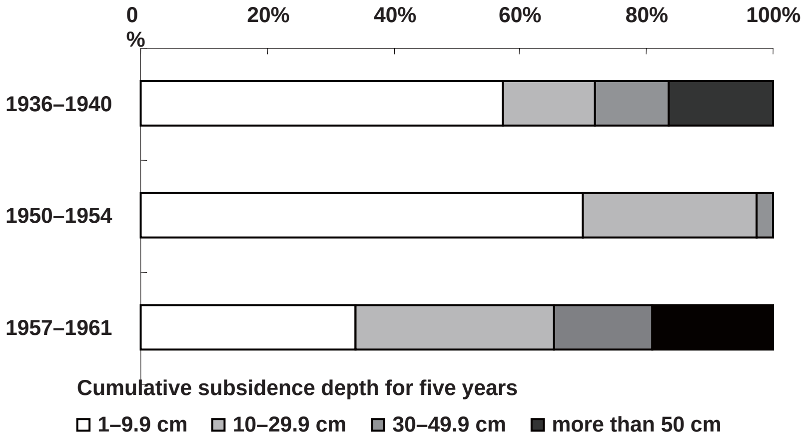

Figure 5. Expansion of land subsidence in Osaka, 1936–1961

Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1972.

The Industrial Water Law was amended in 1962 to strengthen control of groundwater abstraction. In addition to restricting new well construction, pumping from existing wells also became regulated. Under the amendment, abstraction from wells with an outlet size more than 6 square centimeters and a depth up to 500–600 m was prohibited in the city, which meant that smaller and deeper wells came under control of the law, making groundwater abstraction by industries in the city illegal.

In the same year that the Industrial Water Law was amended, another national law on groundwater control, the Law Concerning the Regulation of the Pumping-up of Groundwater for Use in Buildings (the Building Water Law), was enacted to regulate groundwater pumping for use in buildings. The Building Water Law was different from the Industrial Water Law in that it did not mandate provision of an alternate water source as a condition of groundwater control. This was because groundwater demand for building use could be reduced by introducing water-saving technologies such as cooling towers.

b. Construction of industrial water supply works to provide an alternate water supply to replace groundwater

As mentioned above, provision of alternative water sources by industrial water supply works (IWSW) was a pre-condition of controlling groundwater pumping under the Industrial Water Law. Local governments (prefectures or 12 ordinance-designated cities) were made responsible for the construction and operation of IWSWs. In Osaka city, construction of an IWSW plant had already started in 1951 as a measure to reduce industrial groundwater abstraction, and it began to supply surface water to industries even before the Industrial Water Law was enacted.

After the Industrial Water Law was amended in 1962, IWSW water supply was expanded through new plant construction and expansion of supply capacity, in accordance with the groundwater abstraction restriction schedule (figure 6). The IWSW expansion project was completed in December

1968 and covered all the designated area with 575,500 m^3/d of total capacity (Osaka City Waterworks Bureau 2005).

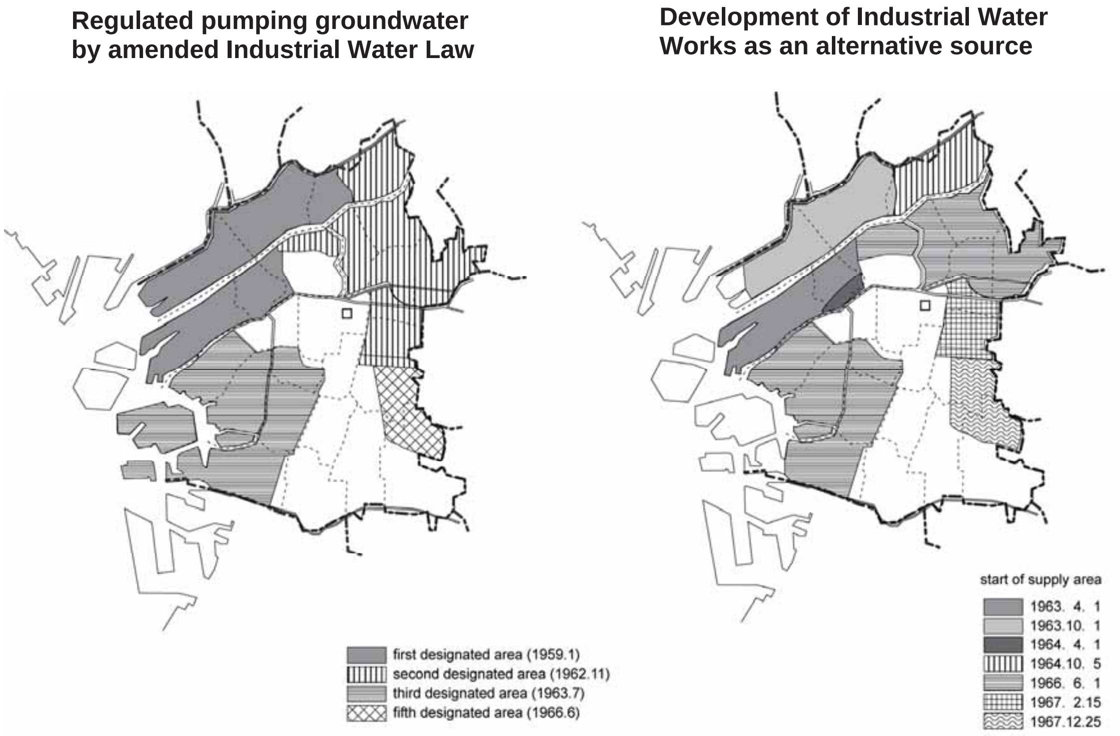

Figure 6: Areas designated under the Industrial Water Law and provision of industrial water supply works

Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1971.

The chronological change in IWSW tariffs in Osaka is shown in table 2. The tariff in 1954, 6.8 yen/m^3, was calculated based on the cost of construction and operating the IWSW at that time. It was estimated that the cost of groundwater abstraction was about 3–4 yen/m^3; therefore, the cost of industrial water supply was a little higher than the cost of groundwater abstraction. After the Industrial Water Law was enacted, the national government began providing subsidies for the tariff in order to set the IWSW water price as low as the cost of groundwater abstraction. To ensure regular revenues, the volume of water to be purchased by individual industries was set (the contracted volume), and industries had to pay for the contracted volume even if they used less water.[4]

4. This policy to subsidize the IWSW tariff was often criticized as a barrier to promoting more rational use of water in the industrial sector (Shimazu 1981).

Table 2. Tariff history of the Osaka City Industrial Water Supply Works, in yen/m^3

Year	Apr. 1954 to Mar. 1959		Apr. 1959 to Mar. 1964	Apr. 1964 to Mar. 1965*	Apr. 1965 to July 1969	Aug. 1969 to Mar. 1970	Apr. 1970 to Mar. 1971**	Apr. 1961 to Feb. 1973	Mar. 1973	Apr. 1973 to Oct. 1974	Nov. 1974 to Nov. 1977	Dec. 1977 to Apr. 1984	May 1984 –
Tariff***	6.8	Contracted volume	4	(a) 4 (b) 5.5	5.5	6 5.5	(A) 6.5 (B, C) 5.5	7	8	10	17	27	35
		Over the contracted volume	6	(a) 6 (b) 11	11	12 11	(A) 13 (B) 11	14	16	20	34	54	70

Source: Osaka City Waterworks Bureau 2005.

* A different tariff was set for the two designated control areas in the Industrial Water Law: (a) for the first and (b) for the second.

** A different tariff was set for three different control areas by the Industrial Water Law: (A) to the first designated area except a part of Higashiyodogawa-ku, (B) to the second and third designated areas and the part of Higashiyodogawa-ku excluded in the first designated area, and (C) other areas of the city.

*** A consumption tax was imposed April 1, 1989. It was increased from 3 percent to 5 percent in April 1999.

c. Subsidies and favorable tax treatment for installation of water-saving technologies

Municipal governments provided subsidies and/or favorable tax treatment for installation of water-saving technology such as cooling towers, in particular for groundwater users regulated under the Building Water Law. Financial support in the form of a favorable tax and low rate loans was also provided to install the necessary equipment to receive water from industrial water works.

3.5. Effectiveness of the intensive measures to manage groundwater

a. Gaining control of the dropping water table and land subsidence

As figure 7 shows, groundwater abstraction by the industrial sector dramatically decreased and shifted to the IWSW water supply between 1963 and 1969, following the restriction schedule set out in the Industrial Water Law. Groundwater abstraction for building uses also sharply decreased for a few years after the Building Water Law was enacted in 1962. This reduction was achieved solely by the introduction of water conservation technologies, without provision of other water sources. As a result, the groundwater level began to rise and the land stopped sinking.

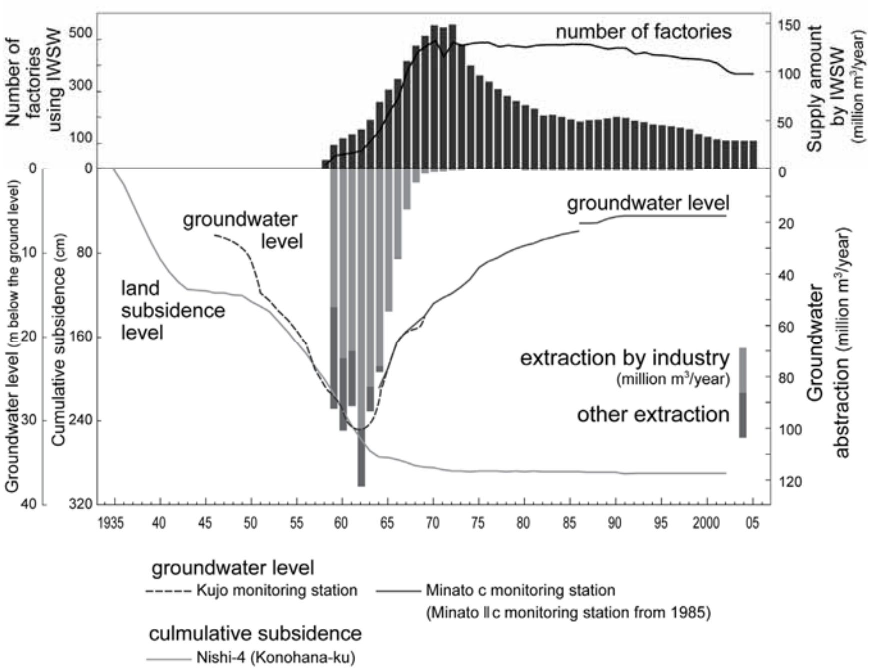

Figure 7. The shift from groundwater to industrial water works for water supply in Osaka

Sources: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993. for land subsidence and groundwater level. Osaka City Water Works Bureau 2005. for the data of industrial water supply works.

In addition to the three elements of control measures (regulations, provision of alternative water sources, and financial and technical support), the following should be mentioned as enabling factors in the success of the city of Osaka in reducing groundwater use:

- Land subsidence was monitored by the city government for more than three decades, which helped in policymaking.
- The Committee on Comprehensive Countermeasures against Land Subsidence in Osaka was established as a platform of discussion on land subsidence issues between local governments (municipal and prefectural) and the industrial sector to tackle the problem.
- The main users of groundwater were industries and large buildings, and therefore control measures focused on these two sectors.
- Surface water was available as a source for the industrial water supply works.

b. Deficiency—Lack of a comprehensive groundwater basin management strategy

Although intensive measures in Osaka effectively mitigated groundwater problems, when considering groundwater problems at the groundwater basin level, the delay in introduction of groundwater control in neighboring administrative areas caused the worsening of negative impacts of land subsidence. For example, in Higashi-Osaka area, which is also located in the Osaka Plain, the drop in water table and land subsidence intensified in the late 1960s to early 1970s, while land subsidence had already stopped in the city of Osaka. It was five years later than Osaka that the Industrial Water Law was designated to apply to Higashi-Osaka. In 1971, the Osaka Prefectural Ordinance was enacted to mitigate land subsidence in the rest of the city area. The delay in the introduction of countermeasures intensified the incidence of land subsidence that could not be reversed. The countermeasures should have been introduced beyond the administrative boundaries.

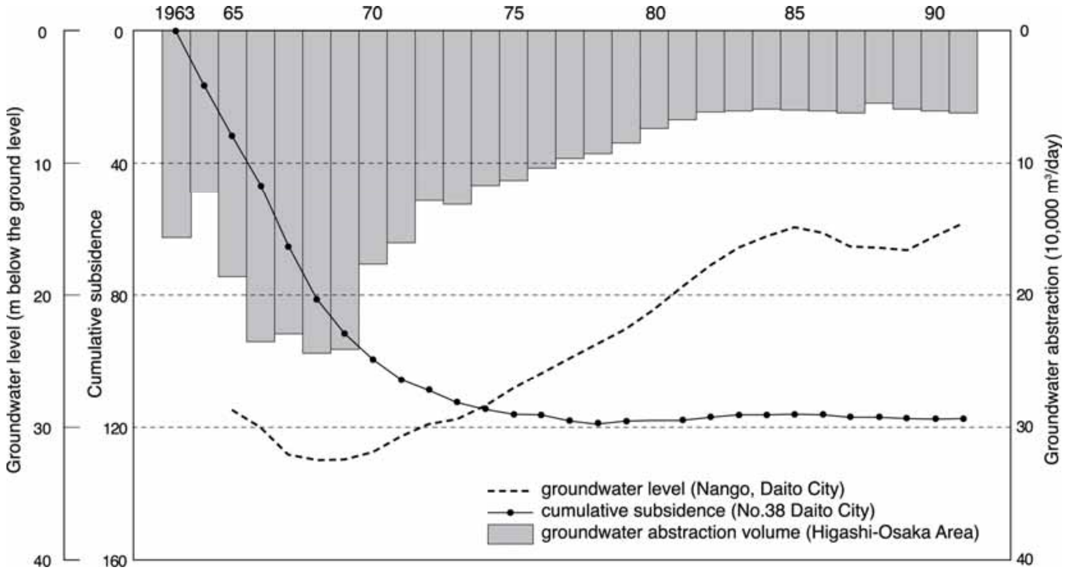

Figure 8. Cumulative subsidence depth and drop in the water table in Higashi-Osaka

Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993.

3.6. Experiences of other Japanese cities and the uniqueness of Osaka's situation

In other Japanese cities, with different socioeconomic and environmental backgrounds, the effectiveness of the same policy measures was different from that in Osaka. For example, it took more time in Tokyo to reduce groundwater abstraction,[5] although the two national laws applied there as well. The availability of surface water as an alternate water source was one of the differences between the two. As it was difficult to acquire the rights to river water for IWSWs in Tokyo, this alternate supply could not be provided right away. As well, wastewater was also utilized as a source of IWSW in Tokyo, but industries there hesitated to use it because of concerns about consistent water quality. So the Tokyo metropolitan government's efforts to rationalize water use were constrained through the Pollution Control Ordinance issued by the metropolitan government, compared to the situation in Osaka.

5. In Tokyo, land subsidence was caused by both over-exploitation of groundwater and natural gas abstraction. Therefore, land subsidence ceased after the introduction of measures to control natural gas abstraction in addition to groundwater abstraction.

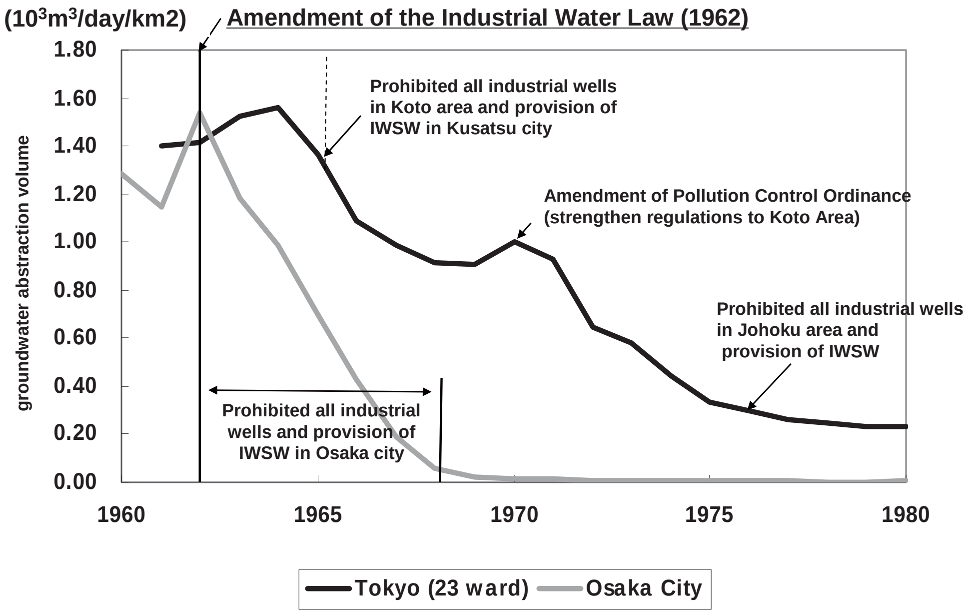

Figure 9. Comparison of groundwater abstraction in Osaka and Tokyo's 23 wards, 1960–1980

Sources: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka. 1993. for abstraction data of Osaka; Tokyo Chikasui Kenkyukai. 2003. for abstraction data of Tokyo.

Looking at other cities, the rationalization of water use seemed to contribute substantially to the reduction of groundwater abstraction by the industrial sector. For example, in the city of Hiratsuka in Kanagawa Prefecture, industrial groundwater abstraction was successfully decreased through rationalization of water use. The city government set individual caps on groundwater abstraction for factories through negotiation and also encouraged water rationalization practices. As a result of promoting water conservation, total groundwater pumpage decreased from 100,000 m^3/d in 1972 to about 50,000 m^3/d in 1975 (Mizu Syushi Kenkyu Group 1993). In accordance with the reduction of groundwater pumpage, the incidence of land subsidence in the city was also halted, and in 1976 the city declared that it had succeeded in stopping land subsidence. An analysis by Shibazaki (1981) showed that the introduction of wastewater treatment charges for industries was an incentive for them to reduce water use. It is estimated that industries had to spend 28–56 yen/m^3 for wastewater treatment, while the investment cost for water-saving technology was about 19.5 yen/m^3, and this economic advantage of water conservation motivated them to reduce their water consumption.

Water pollution control measures strengthened in 1970s also contributed to promotion of water rationalization in the industrial sector. In order to meet effluent standards, industries had to introduce wastewater treatment technologies. They had to pay wastewater treatment charges. To minimize costs of wastewater treatment, industries tried to reduce the water inputs and also promote water recycling in the factories. In addition, the energy crisis (or oil shock) in 1973 further served to promote energy conservation practices in the industrial sector. The change in social consciousness became a driving force to promote water rationalization in industrial activities, which contributed to a reduction of groundwater pumpage in Japan, as seen in Tokyo and Hiratsuka[6].

As shown in figure 10, Osaka also experienced a sharp increase in water recycling and reuse in 1970. If the city had failed to control groundwater abstraction in 1960, water rationalization would have been a promising option for groundwater management. However, for the city, the incremental cost incurred by the introduction of IWSW water might have been the motivation for industries to employ water conservation, contrary to the experiences of Tokyo and Hiratsuka.

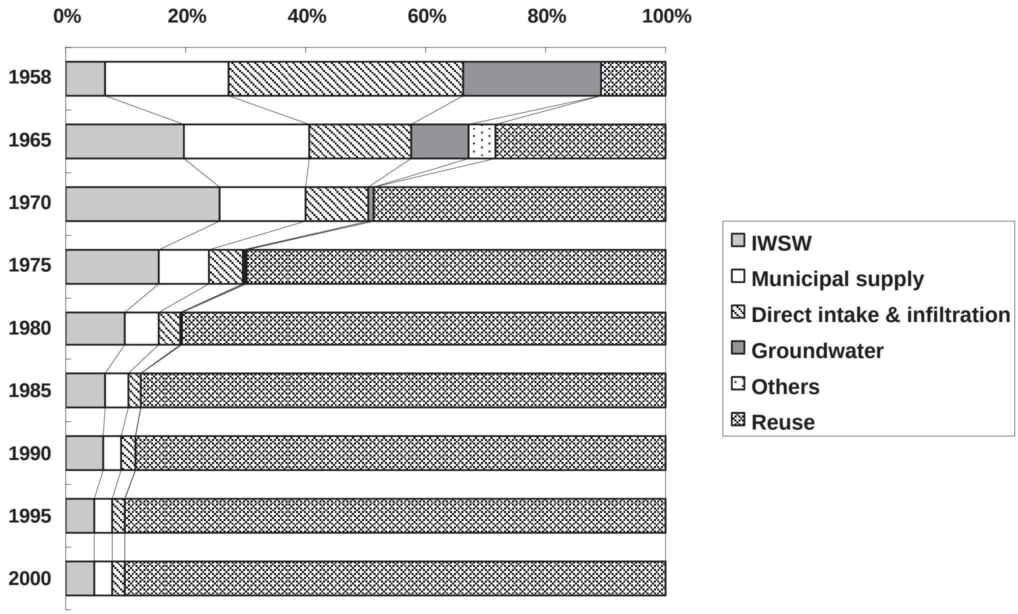

Figure 10. Freshwater supply for the industrial sector, by source

Source: Research and Statistic Department of Ministry of International Trade and Industry 1960, 1967, 1972, 1977, 1982, 1987, 1992, 1997. Research and Statistic Department of Ministry of Economy, Trade and Industry 2002.

3.7. Long-term impacts of regulating groundwater pumping

More than fifty years have passed since groundwater control measures were introduced. The intensive measures have helped to maintain and conserve groundwater resources, but some contradictions were observed.

6. Current groundwater management policy in Japan includes promotion of water rationalisation as a tool to control groundwater abstraction, but this element was not fully considered in the earlier groundwater management.

a. Increase of the groundwater level and the effective use of available resources

Strict groundwater control policy succeeded in mitigating falling groundwater levels and land subsidence in Osaka. The groundwater level has been rising as a result of the pumping regulations for about half a century, but this has caused damage to subway stations and water seepage and uplifting problems in underground structures. The rise of the water table may also increase the possibility of a liquefaction incident during an earthquake and therefore could intensify the damage to building infrastructure.

To prevent such negative impacts of a higher groundwater table, groundwater should be abstracted and used more effectively. There is still a need for scientific study on safe yield levels, but the groundwater management policy should nevertheless be regularly reviewed and updated according to the current situation.

b. Decrease in demand for water from industrial water supply works

Figure 7 shows that IWSWs played an important role in controlling groundwater abstraction in Osaka. One of the advantages of the IWSW scheme is that construction of IWSW plants was rather simple and therefore they could be built relatively cheaper and quickly. The water treatment process can also be simpler, because quality control is less restricted than treating water for drinking (Aya and Matsumoto. 2003). In other Japanese cities, IWSW plants were constructed for more effective water supply to industries rather than to control groundwater abstraction.

Figure 7 also shows, however, that the volume of IWSW water supply has been decreasing since 1974. As a result, IWSW revenues have also decreased. As a part of management restructuring, downsizing of supply capacity and even a plant shutdown were conducted. Since 1973, with permission of the Ministry of Economy, Trade and Industry, the Osaka IWSW began to supply water to the city government's facility in order to sell more of their water. Currently, 23 percent of the total IWSW water supply in Osaka is sold for non-industrial use (Osaka City Waterworks Bureau 2005). Figure 11 shows that the IWSW capacity utilization rate is now only 50 percent. If it were based on the average supply amount, then the rate would be less than 40 percent. As the IWSW was originally built for the industrial sector, it is not easy to sell the water for other uses. This challenge is a common management problem for IWSWs in Japan.

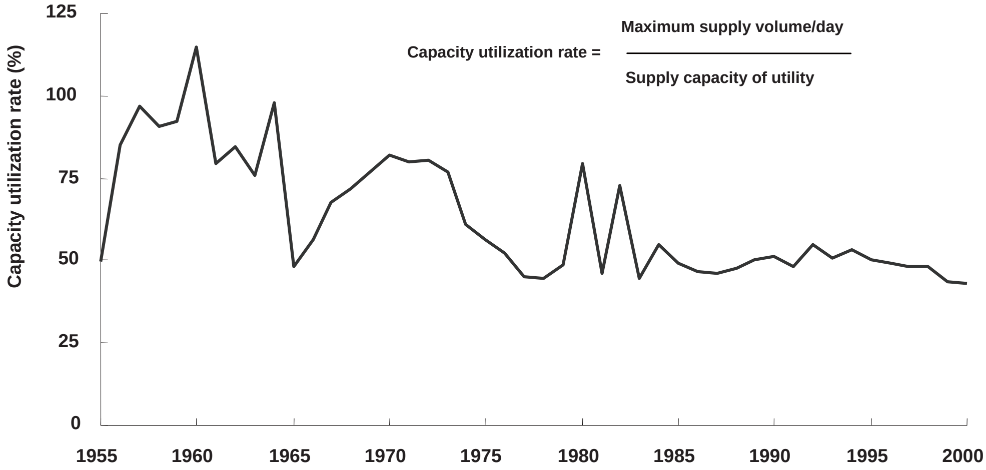

Figure 11. Capacity utilization rate of the Osaka IWSW

Source: Osaka City Waterworks Bureau 2005.

The main reason for the decrease in demand for IWSW water was the increase in the rate of water recycling and reuse, as seen in figure 10. In the case of Osaka, as mentioned earlier, industries had to pay more for IWSW water. In addition, industries had to pay a tariff on sewage, and the city also introduced a progressive charging system for sewage, with large water users having to pay more than those that consumed less. At the same time, there was an additional charge on sewage based on wastewater quality (biological oxygen demand and chemical oxygen demand) introduced in 1974 (Takahashi 1992). This pricing system was designed as a water pollution control measure, but it also contributed to water rationalization by industries. In addition, national water policy encouraged water recycling and reuse in the industrial sector through financial and technical support to try to find a balance between limited water resources and growing water demands. Rationalization of water use in industry itself is a very good trend, but the current situation of IWSWs shows that groundwater management should be designed more closely linked with plans of other areas of water management such as surface water development, improvement of water efficiency, and pollution control. The IWSW experience also tells us that countermeasures to control groundwater should be flexible enough to cope with changes in water demand as a result of changes in social and economic conditions.

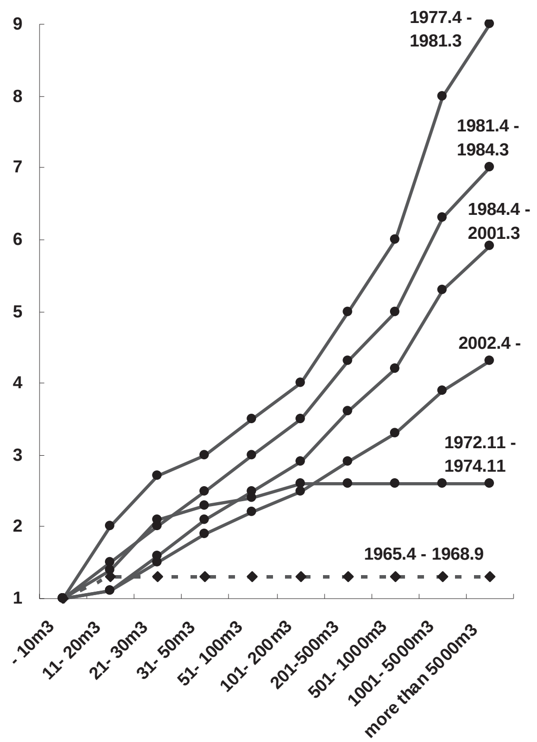

Figure 12. Progressive rate of sewage charges in Osaka

Source: Takahashi 1992.

c. Potential demand for groundwater

After a half century of implementing control measures, it appears that groundwater is a resource that can be safely utilized again, and it is worth considering how to utilize surplus groundwater in Osaka without causing problems. On the other hand, the current trend of groundwater use in neighboring cities with less strict groundwater controls shows that the city needs to consider groundwater management in a bigger context of overall water management in the region.

Recently, groundwater use by private water supply schemes for specific users, called *senyo-suido*, has been increasing in Osaka Prefecture. Senyo-suido is defined in the Waterworks Law as waterworks "for individual specific users of which the number is more than 101 persons and/or the maximum supply amount per day exceeds 20 m^3." Individual waterworks were often introduced for domestic use in areas without public water supply, but the recent trend shows an increase in individual waterworks using groundwater as their primary source. Large users of public water supply, such as hotels, fitness clubs, hospitals, and retail stores, are the main owners (users) of senyo-suido, and one of the major reasons why they use it is the lower cost of water.

Under the current tariff structure for municipal water supply, heavy users have to pay more than individual customers. Consequently, a decrease of water demand from heavy users can directly affect the business of a municipal water supply plant, and it is presently a big problem for public water supply schemes, because it threatens the economic viability of public waterworks.

In 2003, for example, 23 commercial-scale utility customers in Osaka Prefecture introduced their own water supply systems (based primarily on groundwater), the largest number compared to other prefectures. This resulted in a loss of revenue from April 2003 to March 2004 for the Prefectural Public Waterworks estimated at 350 million yen (Osaka Prefecture 2004). The city of Kusatsu in Shiga Prefecture, faced with an increase of groundwater use by commercial-scale users, reduced the tariff for large users (Okuno 2004). In addition, the city decided to publish the names of heavy water users who intended to stop or greatly reduce their purchases from the public water supply scheme.

Groundwater should be effectively utilized where it is available. As the case of groundwater use in individual water works illustrates, the expansion of groundwater use can affect the economic viability of the existing water supply scheme. If public water supply provides cheaper water to heavy users in order to keep them using the public supply scheme, then there may be a risk of wasteful water use.

One of the possible solutions to the problem is to introduce a charge system for groundwater abstraction, although more discussion is needed on how to calculate the appropriate price. In Japan, however, groundwater abstraction rights belong to those who own the land, in principle, making it difficult to charge a groundwater use fee.

4. Conclusion

Without any control measures, groundwater is easily depleted by over-exploitation. On the other hand, if properly managed, groundwater is a very reliable resource that provides various benefits.

This case study of groundwater management in Osaka provides several lessons for future policymaking in Asian cities. For example, the study shows that the provision of alternative resources with strict regulation of groundwater pumping can effectively reduce pumpage volume. Under a critical state of groundwater resources in the course of industrial development, the intensive measures implemented in Osaka might be useful. As a long-term result, however, as the experience of the city revealed, intensive control of groundwater can increase the availability of the resource and allow its use again under proper control. In Bangkok, groundwater abstraction has been reduced to control the dropping groundwater level and land subsidence, but the city should not take the same path as Osaka in the future. While concentrating on controlling groundwater abstraction, it may be necessary to examine how to sustainably utilize groundwater, and this should include studies of past experiences elsewhere. Such a medium- and long-term perspective of management should be incorporated into policymaking and implementation.

The importance of demand management should also be more emphasized in groundwater management. The sharp decrease of water demand in the industrial sector in Osaka, which caused management problems for the local IWSW showed a great potential for rationalization of water use as a groundwater management measure. A quick review of current groundwater management policy in Asian cities, however, reveals that encouragement of water conservation practices in the industrial sector is not well incorporated, or such an effort has been promoted in the other area of water management. In order to reduce water inputs, efficient utilization is a very primary but important element of management of limited water resources, including groundwater. User fees or taxes are one of the tools that can control water demand. Altering water demand is very crucial for the management of other water sources, and therefore more comprehensive or integrated water management policy design should be promoted to avoid unnecessary wastefulness and damage to water resources.

Acknowledgement

This study was conducted under Sustainable Water Managment Policy (SWMP) project - a sub-component of the Freshwater Resources Management Project, Institute for Global Environmental Strategies (IGES). The author would like to thank the research partners of the research of SWMP for their valuable support. The author would like also to thank the staff of the Osaka Prefectural and City Governments for providing data and information for this study.

References

Asian Institute of Technology (AIT). 2006. SWMP study on groundwater management, Bangkok, Thailand (unpublished).

Aya H., and K. Matsumoto. 2003. Water for sustainable development of industry—Role and contributions of industrial water supply works in Japan (in Japanese). *Kogyo Yosui* (Japan Industrial Water Association) 537:2–12.

Babel, M., and N. Donna. 2006. SWMP final report—Bangkok (unpublished).

Bumatay, C. G. 2004. Water use in Metro Manila and Metro Cebu. Proceedings of the 2nd APHW Conference (APHW 2004) in Singapore jointly with the 1st Asia Oceania Geosciences Society (AOGS) Conference, http://www.wrrc.dpri.kyoto-u.ac.jp/~aphw/APHW2004/proceedings/JSE/56-JSE-A621%20(PDF%20only)/56-JSE-A621.pdf, (accessed December 20, 2005).

China Daily. 2003. Shanghai still sinking (2003-11-19 10:27), http://www.chinadaily.com.cn/en/doc/2003-11/19/content_282844.htm.

Committee on Comprehensive Countermeasures against Land Subsidence in Osaka. 1972. Osaka jiban chinka taisaku shi. Osaka [History of countermeasures against land subsidence in osaka]. Isshindo Insatsu.

———. 1993. *30 syunen kinen shi* [Commemorative publication of 30 years anniversary of the Committee]. Osaka: Kinki Insatsu.

Custodio, E., and M. R. Llmas. 2003. Intensive use of groundwater: Introductory considerations. In *Intensive use of groundwater, challenges and opportunities*, ed. E. Custodio and M. R. Llmas, 3–12. Swets & Zeitlinger B. V., Lisse, The Netherlands.

Dan, N. P., B. X. Thanh, L. V. Khoa, and B. D. Truong. 2005. Country report—Ground water resource management in Ho Chi Minh City (unpublished).

Global Environment Centre Foundation (GEC). 1994. *Osaka-shi kogai taisaku-shi* [Record of pollution control in Osaka City]. Osaka: Kinki Insatsu Pro.

Japan Society of Civil Engineers Kansai Chapter. 2002. Chikasui seigyo ga jiban chinka ni oyobosu eikyo hyoka [Assessment of the impact on the geo-environment by groundwater control]. Japan Society of Civil Engineers Kansai Chapter. Osaka.

Japan Water Works Association. 2005. Chikasui riyo senyo suido no kakudai ni kansuru hokokusyo [Report on increasing individual water works that use groundwater as a source], http://www.jwwa.or.jp/pdf/senyou_suidou.pdf (accessed August 30, 2005).

Mizu Shigen Syushi Group. 1993. Chikasui shigen no hyoka to kanri [Evaluation and management of groundwater resource] . In *Mizu Syushi Kenkyu Group* ed. Chikasui shigen kankyo ron—Sono riron to jissen [Theory and practice of conservation of groundwater resource], 273–311. Tokyo: Kyoritsu Syuppan.

Morris, B. L., A. R. L. Lawrence, P. J. C. Chiltion, B. Adams, R. C. Calow, and B. A. Klinck. 2003. *Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management.* Early warning and assessment report series, RS. 03,3. Nairobi: United Nations Environment Programme.

Nankai University. 2006. Case study for Tianjin, China—Revised analysis report on groundwater management policy (unpublished).

Okuno, T. 2004. Oguchi suido riyosya no chikasui tenkan wo yokuseisuru mokuteki de jisshishita Kusatsu Suido Jigyo Secchi Joreito no kaisei keii ni tsuite [Amendment of an ordinance on Kusatsu water works for prevent heavy water users from transferring their water source to groundwater from public water works]. *Journal of Japan Water Works Association* 73 (5): 32–37.

Osaka City. 1957. Kogyo yosuido jigyo-hi hojyokin kofu shinsei syo [Application for the subsidy to construction of industrial water supply works to the Minister of International Trade and Industry].

Osaka City Comprehensive Planning Bureau. 1963. *Jiban chinka ni kansuru shiryo* [Document on land subsidence].

Osaka City Environment and Sewage Bureau. 2004. Jimu jigyo gaiyo FY 2003 [Annual business report FY 2003].

Osaka City Planning Bureau. 1960. *Jiban chinka ni kansuru shiryo* [Document on land subsidence].

Osaka City Waterworks Bureau. 2000. Water supply in Osaka.

———. 2003. Environment report FY 2002.

———. 2005. Osaka shi kogyo yosuido 50 nenshi [History of 50 years of the Osaka city industrial water supply works].

Osaka Prefecture. 2004. Chikasui wo suigen to suru senyo suido mondai ni tsuite [Individual water supply with groundwater as a source], http://www.pref.osaka.jp/suido/jouhou/hyoka/1602hyok/8sensui.pdf (accessed November 10, 2005).

People's Daily Online. 2003. Cities sinking due to excessive pumping of groundwater, http://english.people.com.cn/200312/11/print20031211_130178.html.

Research and Statistic Department of Ministry of International Trade and Industry. 1960. *Census of Manufactures — Report on Industrial land and Water FY1958*. Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

———. 1967. *Census of Manufactures — Report on Industrial land and Water FY1965*. Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

———. 1972. *Census of Manufactures — Report on Industrial land and Water FY1970.* Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

———. 1977. *Census of Manufactures — Report on Industrial land and Water FY1975.* Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

———. 1982. *Census of Manufactures — Report on Industrial land and Water FY1980.* Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

———. 1987. *Census of Manufactures — Report on Industrial land and Water FY1985.* Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

———. 1992. *Census of Manufactures — Report on Industrial land and Water FY1990.* Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

———. 1997. *Census of Manufactures — Report on Industrial land and Water FY1995.* Tokyo: Research Statistic Department of Ministry of International Trade and Industry.

Research and Statistic Department of Ministry of Economy, Trade and Industry. 2002. *Census of Manufactures — Report on Industrial land and Water FY2000.* Tokyo: Research and Statistic Department of Ministry of Economy, Trade and Industry.

Shimazu, T. 1981. Mizu ha amatte iru, mizu jyuyo no jittai wo tsuku—Kogyo-toshi Fukuyama no mizu mondai [Abundance of water —what is a reality of water demand — water issues in Fukuyama city]. *Gijyutsu to Ningen* 10 (7): 116–119.

Shibazaki, T. 1981. Chikasui riyo hozen no shinkyokumen, sono chiho bunsanka to tayo-ka ni taioshite [New dimension of groundwater conservation — corresponding to localization and diversification]. In *Gendai no Mizu Mondai (Julist Zokan Sogo Tokusyu 23)*, 57–64. Tokyo: Yuhikaku.

Takahashi, T. 1992. Osaka-shi ni okeru gesuido shiyoryo seido ni tsuite [Wastewater treatment charge in Osaka city]. in Osakashi Gesuido 20 syunen kinen gyoumu kenkyu ronbunsyu. Osaka: Osaka City Sewerage Engineering Association.

Tokyo Chikasui Kenkyukai ed. 2003. Mizu junkan ni okeru chikasui yusui no hozen [conservation of groundwater and spring water in a water cycle] . Tokyo: Shinzansya Scitech

Xunhua News Agency. 2005. North China's large city to lift water price, September 30, 2005, http://english.people.com.cn/200509/30/eng20050930_211756.html, (accessed December 20, 2005).

West Java EPA. 2006. Analysis final report—Groundwater management, Bandung (unpublished).