CHAPTER 1

COMPARATIVE STUDY OF GROUNDWATER MANAGEMENT - based on the case studies in Asian cities -

This chapter presents a summary of the comparative analysis of the status of groundwater resources, existing policy measures and future challenges for six case study cities, namely Tianjin (China), Bandung (Indonesia), Colombo and Kandy (Sri Lanka), Bangkok (Thailand) and Ho Chi Minh City (Viet Nam). The case of Osaka and Tokyo (Japan) is also cited as a reference case. The status of groundwater resources and the policy measures implemented differ from city to city, but the case study cities share some common challenges in groundwater management. In addition, the social, economic, cultural, and environmental circumstances differ in each city. The situational analysis intends to identify such common challenges through the analysis of key elements in groundwater resources management.

The data referred to in our analysis was provided by each case study report, unless otherwise noted. In our study, we adjusted and interpreted the available data as much as possible to represent the true picture of the case study cities. However, it is necessary to note that the availability of reliable data is limited. To promote sound groundwater management, further scientific research should be conducted.

1. Background to the Case Study Cities

1.1 Socioeconomic Condition

(1) The common feature of the case study cities is the rapid increase of population in the course of economic development. Figure 1 shows the trend of increase of population. The population of Bangkok and Colombo doubled in 30 years, and the increase characterizes the trend of urban sprawl. The registered population—and in some cities such in Ho Chi Minh City, the unregistered population—in each city is substantial. Population density ranged from 3,944 person/km^2 in Kandy to 926 persons/km^2 in Tianjin. The values presented here show only the average population of the case study areas in their entirety, although the distribution of the settlements is highly uneven. For example, in Bangkok, Bandung, and Tianjin, most of the population is concentrated in the so-called city centers with very high population densities.

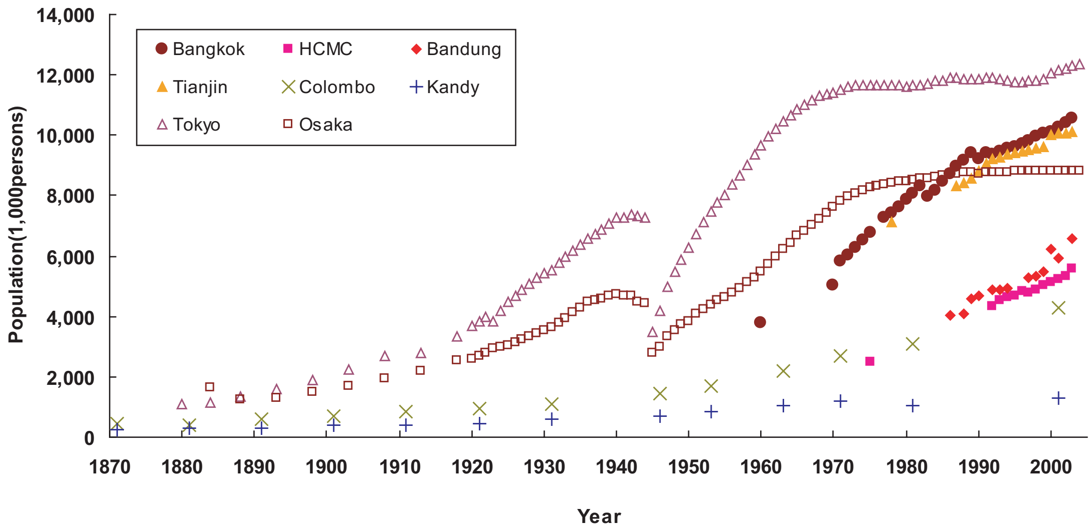


Figure 1. Population Increase since 1870 in Case Study Cities

Note: The population data of Tokyo and Osaka are Tokyo Metropolitan and Osaka Prefecture respectively.

Table 1. Study Area and Population Density

Country	City	Study Area (km²)	Population Density (persons/km²)
China	Tianjin	11,919	926
Indonesia	Bandung	2,341	2,499
Thailand	Bangkok	10,315	1,028
	Bangkok Metropolitan Region	2,844	3,727
Vietnam	HCMC	2,095	2,549
Sri Lanka	Colombo	1,575	2,730
	Kandy	322	3,944
Japan	Osaka	1894	4,567
	Osaka City	222	11,743
	Tokyo	1,781	6,975
	Tokyo 23 Wards	621	20,422

(2) Another common feature of the case study cities is their importance to their respective national economies. Except for Osaka and Tokyo, the per-capita regional gross product far exceeds the national average per-capita GDP in the case study (table 2).

Table 2. Economic Status of Case Study Cities

City	Per-capita RGDP (USD)	National GDP per-capita (USD)
Tianjin	3,212	1,100
Bandung	1,172	940
Bangkok	5,879	2,190
HCMC	1,060	480
Colombo	1,552	957
Kandy	----	
Osaka City	69,661	35,202
(Osaka Prefecture)	(41,600)	
Tokyo Metropolitan	56,986	

1.2 Climatic Condition

The climate of all case study cities except for Tianjin is influenced by a monsoon climate. As these cities have clear rainy and dry seasons, and surface water availability is also highly seasonal. The annual precipitation of each city is shown in the following figure. The figure shows that Tianjin has a very low precipitation, this being a major cause of the city's "water-stressed" situation.

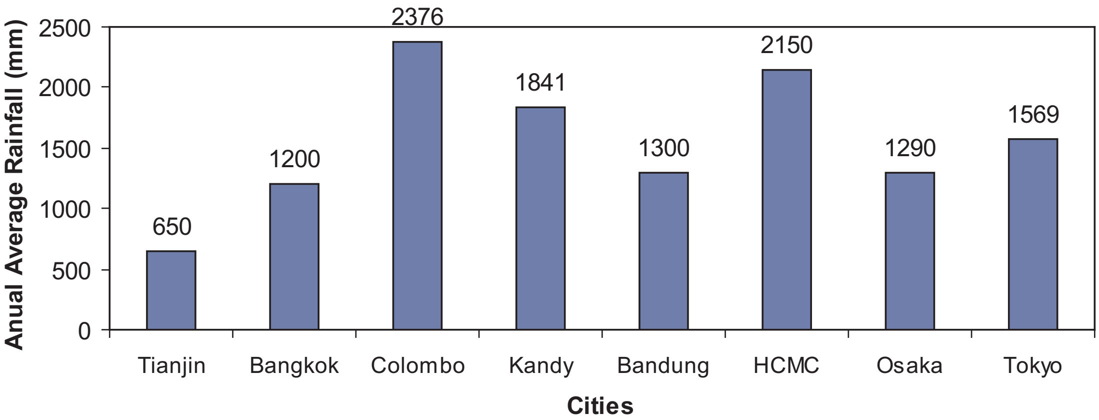


Figure 2. Annual Average Rainfall

Table 3. Average Maximum and Minimum Temperature

City	Average daily max (°C)	Average daily mini (°C)
Tianjin	17.8	8.2
Bandung*	27.2	18.1
Bangkok	32.7	24.1
HCMC	32.3	23.7
Colombo	30.6	24.1
Kandy	29.0	20.2
Osaka**	21.2	13.7
Tokyo**	19.9	13.4

Source: World Meteorological Organization (http://www.wmo.ch/index-en.html)
* *http://indahnesia.com/indonesia/CKI1009.bandung.php*
***http://www.jma.go.jp/jma/index.html*

2. *The State of Groundwater Resources*

2.1 Status of Groundwater Resources

The status of groundwater resources in each case study city differs from city to city. However, roughly speaking, the case study cities share a similar hydrogeological setting of semi- or un-consolidated alluvial sediments, except for Colombo and Kandy which have metamorphic rock formation.

2.2 Groundwater Use

(1) The trend of groundwater use in the case study cities, except for the Sri Lankan cities, is shown in the following figure. Three are three trends of groundwater use, namely (i) intensive use in the past but now stable use under strict control of groundwater abstraction (Osaka and Tokyo); (ii) general trend of increase but with fluctuations in abstraction (Bangkok, Bandung and Tianjin); (iii) trend of continuous increase (Ho Chi Minh City) . The fluctuations in Bangkok after the mid-1980s are partly due to the control measures that have been taken by the government.

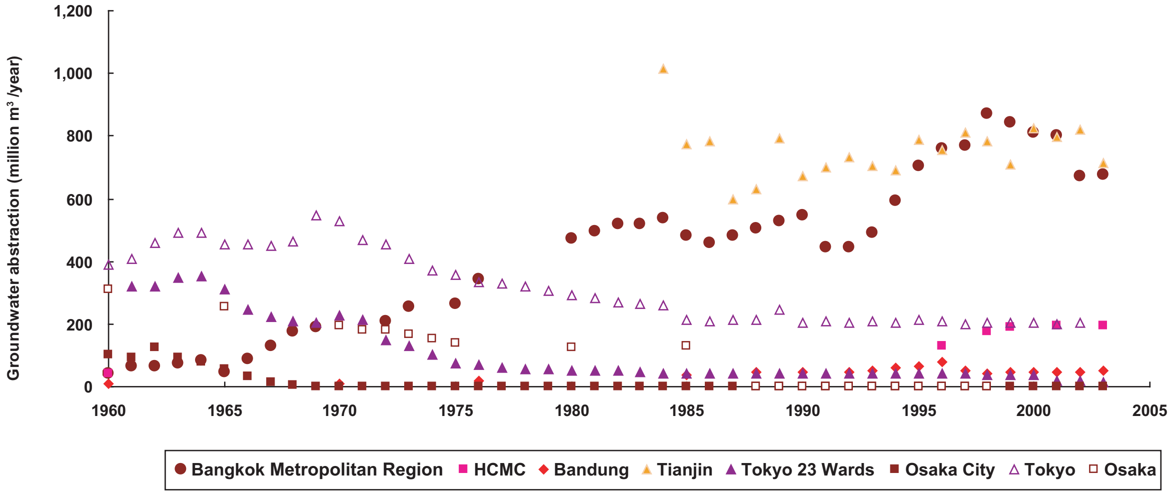


Figure 3. Chronological Groundwater Use in Case Study Cities (except Sri Lanakan Cities)

Note: Bangkok's data is for the Bangkok Metropolitan Region. Osaka's data is only for Osaka City.

(2) When we look at groundwater use per square kilometer, the levels of Tokyo's 23 wards and of Osaka in the 1960's are quite high compared the current abstraction rates of other cities. This demonstrates how intensively groundwater was used in both cities, which resulted in the severe drawdown of water table and the incidence of land subsidence.

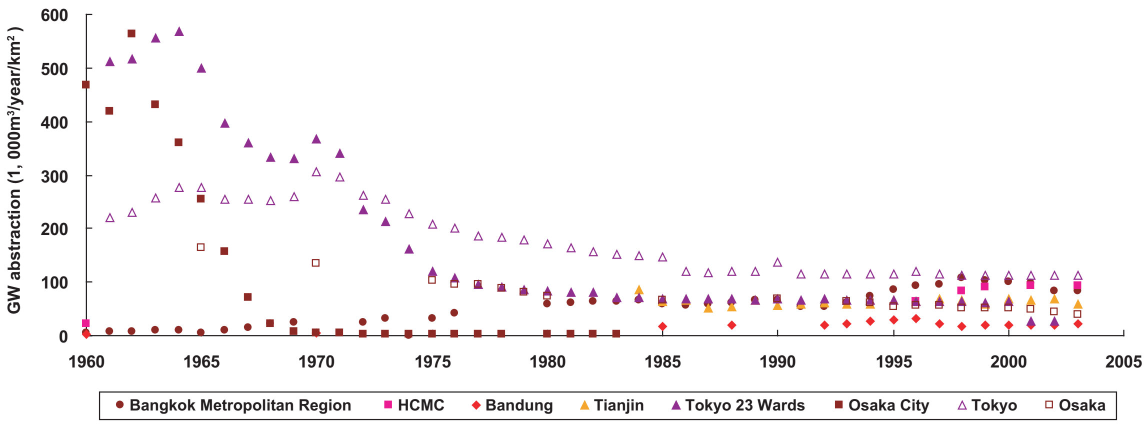


Figure 4. Chronological Groundwater Use on Area per Square Kilometer in Case Study Cities (except Sri Lanakan Cities)

Note: Bangkok's data is for Bangkok Metropolitan Region. Osaka's data is only for Osaka City.

(3) There is a general path of groundwater use, as shown the following figure from Osaka city, when we consider the groundwater use of the case study cities. The first stage is modest use within the sufficient recharging capacity of groundwater. The second stage is intensive use of groundwater that is often triggered by population increase and economic development. In many cases, at this stage groundwater is abstracted without consideration of its recharging capacity and without any effective control measures. Therefore, problems such as drawdown of water table, land subsidence, and salinization caused by overexploitation of groundwater emerge as social problems. The third stage is reduction of groundwater use as a result of groundwater control measures intended to mitigate problems associated by groundwater overuse. In the case of Osaka city, the reduction took place successfully in a short period. However, the case studies of Bangkok, Tianjin, and Bandung show that it takes an extended period of time to see such reduction. The main reasons for this are often the ineffectiveness of the measures and weak enforcement. After successful implementation of the control measures, groundwater use is controlled, which results in mitigation of the problems. This is the fourth stage. Recently, in Osaka, Tokyo and other Japanese cities, increase

of the groundwater level has caused other problems, such as damage to urban infrastructure including subway. It is necessary to consider how groundwater is effectively used without causing problems, as in such cases. The next step is to consider groundwater control measures in which groundwater is used taking into consideration sustainability of the resource.

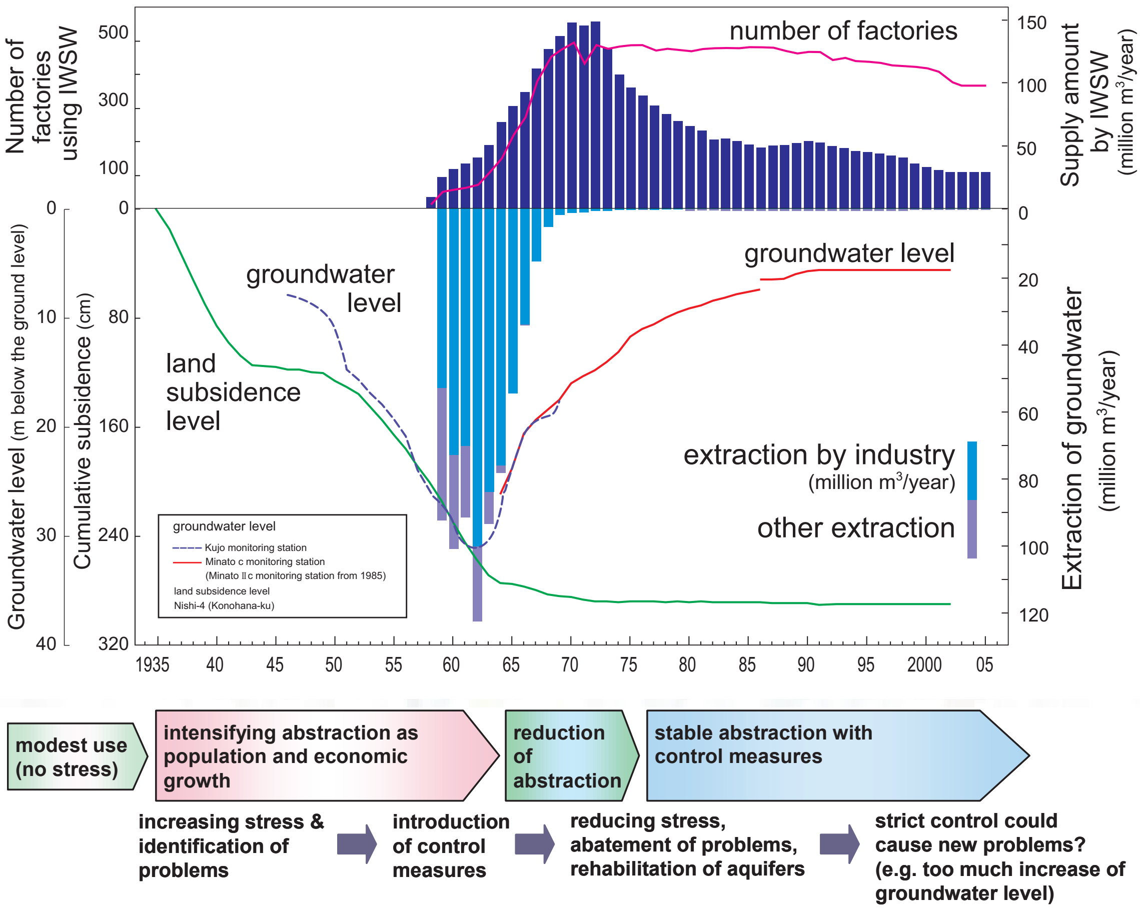
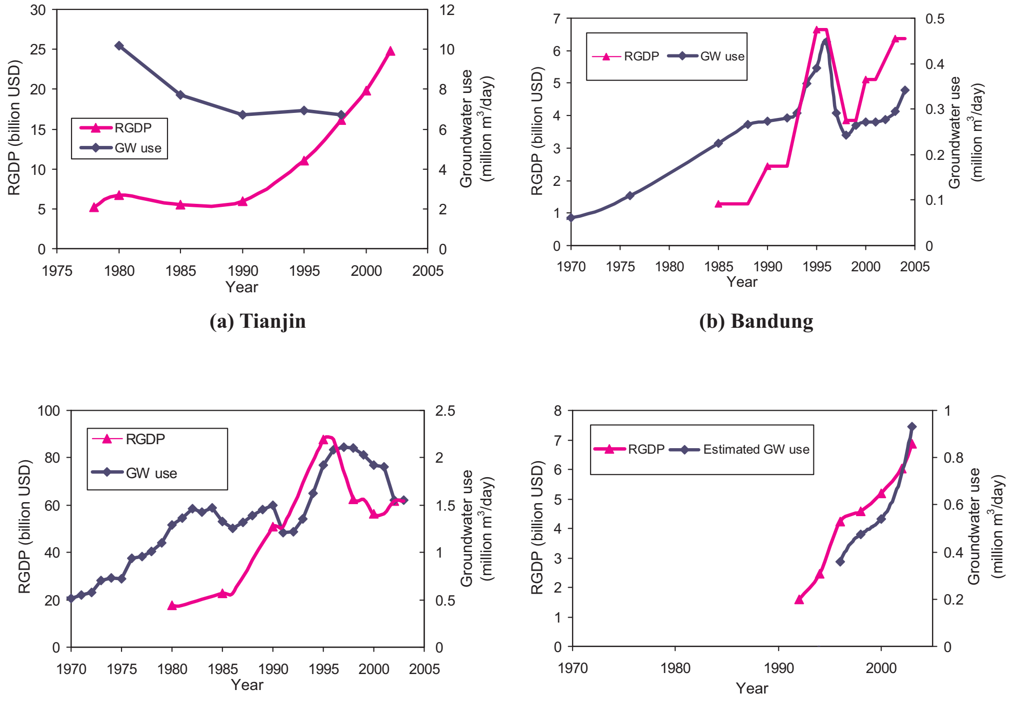


Figure 5. General Path of Groundwater Use (Case of Osaka City)

(4) Groundwater has contributed to the development of cities as an important source for industrial production and as a source of drinking water. Figure 6 shows that there is a strong correlation between historical groundwater use and economic growth (in terms of study area RGDP and industrial RGDP) in Bandung and HCMC. In the case of Tianjin, where groundwater use declined with increased RGDP, however, the trend is the opposite. Bangkok's groundwater use had increased as the city grew since the late 1960s, but recent data on Bangkok now also shows a variation similar to Tianjin. The differences in the correlation between economic development and groundwater abstraction are closely related to the effectiveness of groundwater abstraction control.



(a) Tianjin (b) Bandung

(c) Bangkok (d) HCMC

Figure 6. Historical Groundwater Use and Economic Development in Selected Cities

(5) However, intensive use of groundwater resulted in depletion of the resource, which is t often associated with other problems such as land subsidence and salt water intrusion. Some indicators are shown in Table 4. As Figure 5 indicated, because of intensive abstraction of groundwater, Osaka suffered from severe water table drawdown associated with land subsidence from late 1950 to early 1960. Tokyo also had the same problems at the same time. Tokyo Metropolitan Government has spent 8,391 million JPY for 10 years (1963-1972) at the price as 1972 for measures against land subsidence including constructing banks, banks raising, repairing floodgates, and rehabilitating water pipe, etc. To remedy the negative impacts of land subsidence was expensive. To avoid the problem, a precautionary approach should have been taken.

Table 4. Effects of Intensive Use of Groundwater

Study area	Average drop in water level (m/year)			Average land subsidence (mm/year)		
	1980	1990	2003	1980	1990	2003
Bangkok	1.0	3.0	-1.5	23	25	15
Bandung	1.3	6.5	0.8	-	10	18
Colombo	-	-	1	-	-	-
HCMC	0.1	0.95	1.0	-	-	-
Kandy	-	-	2.5	-	-	-
Tianjin	-	-	0.63	119	15	31

Note: the vaivas in this table not average but apply to spacific locations.
(-) Data is not available

(6) Groundwater recharging capacity became lower because of land use change of the recharging area as a result of urbanisation in cases such as Bandung. This could be one reason for the depletion of groundwater resources. Recharging projects were conducted in some cities, but no successful result has come of them.

2.3 Groundwater Quality

(1) Groundwater quality deterioration is observed in the case study cities. The pollutants differ from place to place, and are even site specific, but naturally occurring pollutants (e.g. fluorine), salinization due to sea water intrusion, and coliform contamination caused by domestic waste water were identified. Due to the pollution, without treatment the groundwater can not be used for drinking.

Table 5. Compliance Ration with Drinking Water Quality in Selected Cities and Aquifers

City (Aquifer)	Year	No. of Sample	Compliance Ratio with WHO guideline for Drinking (%)										
			F	As	Cl	Coliforms	NO3	Mn	Fe	Cr	Hg	Tri-CE	Tetra-CE
Tianjin*	1999	-	5	100	41	-	-	-	-	-	100	-	-
Bandung (Shouldow Aquifer)	2000	35	-	-	-	0**	100	100	94	-	-	-	-
Bangkok (PD/BK Aquifer)	2001	51	100	-	2	-	100	6	0	-	-	-	-
Bangkok (NL Aquifer)	2001	14	86	-	71	-	100	71	43	-	-	-	-
Bangkok (NB Aquifer)	2001	12	100	-	67	-	100	67	17	-	-	-	-
HCMC (Holocen Aquifer)	2004	14	-	-	38	50	100	-	88	-	-	-	-
HCMC (Pleistocen Aquifer)	2004	103	-	100	89	50	99	75	72	-	88	-	-
HCMC (Upper pliocen Aquifer)	2004	64	-	100	78	-	100	61	48	-	89	-	-
HCMC (Lower pliocen Aquifer)	2004	30	-	-	63	-	97	-	57	-	-	-	-
Kandy	2004	14	-	-	-	10	100	-	71	-	-	-	-
Tokyo	2005	71	100	100	-	-	97	-	-	100	100	100	100
Osaka	2005	83	100	99	-	-	100	-	-	100	100	100	100
WHO Guideline for Drinking (mg/l) (MPN/100ml:Coliform)			1.5	0.01	250	0	50	0.5	0.3	0.05	0.001	0.07	0.04

* *Compliance ratio in Tianjin is based on the domestic groundwater quality standard.*

*** Data in 2004*

Tri-CE: Trichloreethylene, Tetra-CE: Tetrachloroethylene

(2) In addition to conventional pollutants such as fluorine, chlorine and coliforms, new contaminants connected with rapid industrialization and intensive agriculture can be future hazards to human health. In Tianjin, from factories involved in the manufacture of chemical, metals and electric machinery which causes heavy metals, and in Japan from VOCs which are common in the industrial sector, come materials which are potential pollutants for groundwater. At the same time, particular attention should be paid to groundwater pollution caused by fertilizers and pesticides. Although the overall area of cultivated land has been decreasing over the past decades, intensive consumption of fertilizers and pesticides is confirmed in these case study cities.

2.4 Problems Associated with Groundwater

(1) The water stress, the ratio of abstracted volume to the renewable ground/surface water that shows the utilization state of water resource in each city are shown in the following table. Tianjin showed a high level of stress on both surface water and groundwater. Further, groundwater abstraction in HCMC exceeds the so-called safe yield (renewable amount) for the area while utilization rate of renewable surface water is 55.2%. On the other hand, the renewable surface water resources are almost fully utilized in Bangkok, while groundwater stress is 23.8%. In Bandung, Colombo and Kandy, the groundwater stress on the available groundwater base is not so high (4.4%, 11.3% and 9.7% respectively) while the value based on the renewable groundwater is not clarified. Because of surface water pollution in HCMC and Bandung, surface water availability is restricted.

Table 6. Water Stress

Resource	Stress (%)*					
	Tianjin	Bandung	Bangkok	HCMC	Colombo	Kandy
Groundwater	- (86.2)**	- (4.4)**	23.8 (4.8)**	121.9 (24.4)**	- (11.3)**	- (9.7)**
Surface Water	73.3	-	103	55.2	20.3	79.7

* *Water stress is the ratio of abstracted volume to the renewable ground/surface water. Figure of abstracted volume or renewable water is cited from case study report of each research partner*

** *Number shown in parentheses for groundwater stress is the ratio of abstracted volume to the available groundwater*

(2) Groundwater is used mainly for industrial or domestic use, except in Tianjin. In Bandung, HCMC and Bangkok, the major users of groundwater abstracted is industry, and future groundwater demand in these cities is contingent on the relationship with the water usage of industry. In Tianjin, however, the predominant use of groundwater is agriculture. In Kandy and Colombo, most of the abstracted groundwater is used by households.

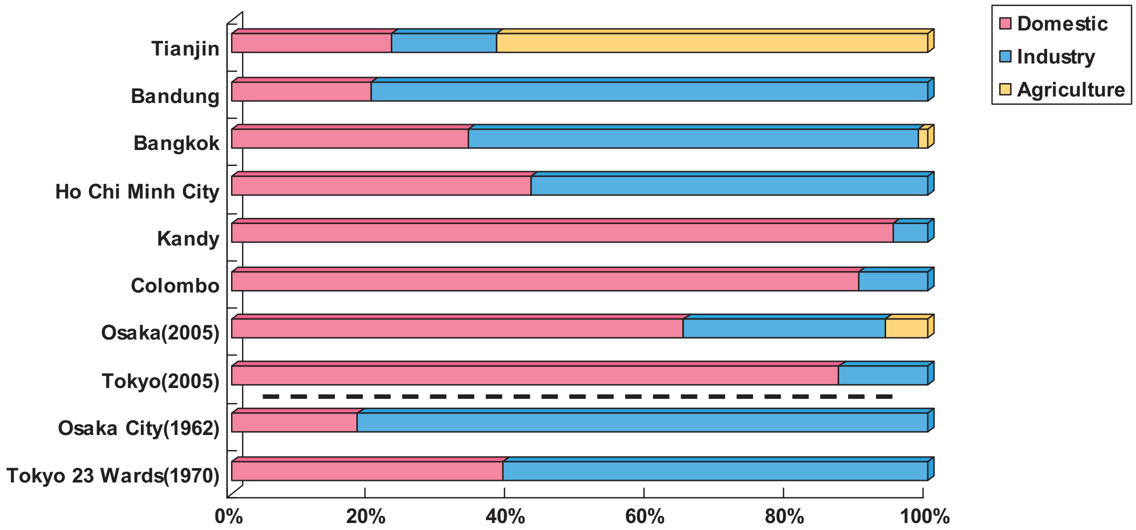


Figure 7. Beneficial Use of Groundwater

2.5 Groundwater Right

By statute in China, Indonesia and Viet Nam, groundwater is defined as being in the public domain, and therefore the government is entitled to manage the resource. In Thailand, while there are no legal document specifying ownership, groundwater is widely recognised as a public good. In Sri Lanka and Japan, groundwater is regarded to be a private domain, and this fact constitutes one of the barriers against the government control of groundwater use in these cities, in particular in Sri Lanka, such as the enforcement of groundwater use permission/licensing system and the introduction of charging scheme to groundwater.

3. The Management of Groundwater Resources

3.1 Summary

(1) To cope with the groundwater related problems, measures to restrict groundwater use have been taken, such as introduction of licensing/permission system and groundwater charging scheme. Provision of other water sources which provide a substitute for groundwater use is also a major measure to reduce groundwater use. Determining how to optimise the combination of available measures according to local situations is the key for the success of groundwater use control.

(2) Groundwater management in the case study cities can be categorized in three groups. For Tianjin and HCMC, restriction or reduction of groundwater abstraction is main issue because of high stress to groundwater resource and environmental problems caused by over abstraction of groundwater. For Bangkok, groundwater stress in general is not so high, but stress to groundwater and environmental problems from over exploitation is concentrated in specific region. So, regional issues are the main concern for groundwater management in Bangkok. For Bandung and Kandy (Colombo), there is no serious problem or issue regarding groundwater management, but establishing a proper management system balanced in integrated water resource management system is an important issue in those cities. The following table shows the overall status of measures taken to control groundwater use in the case study cities.

Table 7. Summary of Major Measures Taken for the Control of Groundwater Use

		Tianjin	Bandung	Bangkok	HCMC	Colombo/ Kandy	Osaka	Tokyo
Direct Control	License system/ permit approval	○	○	○			○	○
	Designation of Critical Zone	○	○	○			○	○
	Setting reduction targets to larger groundwater users			○				○
	Fines to violation	○	○	○			○	○
Indirect Control	Charge to groundwater use	○	○	○				
	Provision of other water resources to alternate groundwater	inter-basin transfer, de-salination, reclaimed water use	planning	surface by pubic supply			surface by public supply	surface and reclaimed water
	Subsidies/tax reduction for introduction of water-saving technologies						○	○
	Provision of technical assistance							
	Establishment of quality standards	○		○	○		○	○
Monitoring	Monitoring of groundwater level	○	○	○			○	○
	Monitoring of land subsidence	○	○	○			○	○
	Monitoring of groundwater quality	○		○	○		○	○

3.2 Characteristics of Groundwater Management in Case Study Cities

(1) In the case of Osaka in the 1960s, a quick shift of industrial groundwater use to surface water brought success in the phasing out of groundwater use by industry and therefore the mitigation of land subsidence in a short period. This shift was made by introducing a new water supply infrastructure called "Industrial Water Supply Works (IWSW)" which provided the industrial sector with water from a more simple treatment technique but at a lower price than the regular municipal water supply (figure 5). Water supply from IWSW as an alternative of groundwater was a conditionality of restriction of groundwater abstraction designated by the Industrial Water Law, a national law for control of industrial groundwater abstraction in critical zones. As stated in the law in its objective, sound industrial development by ensuring rational water supply was a priority of the national policy, while there was a critical need for the control of groundwater use by industries. Regarding groundwater abstraction for air conditioning and flushing purpose for commercial building and apartments, another national law, the so-called "Building Water Law," was enacted in 1962 to restrict abstraction for these purposes. By introducing water-saving processes, such as cooling towers, along with economic incentives (tax reduction), the volume of groundwater abstraction for building use was quickly reduced.

(2) In Tokyo, which had a problem of intensive groundwater use similar to the situation in Osaka, it took longer to reduce groundwater abstraction and thereby mitigate the land subsidence problem. There were two major differences between Tokyo Metropolitan and Osaka. First, in addition to the industrial use of groundwater in the area, groundwater there was being pumped for national gas abstraction. There were no national or local laws to stop abstraction of groundwater to use for national gas abstraction, the right of which was recognised to be private, and it was, therefore, difficult to regulate the practice. In 1972 the Tokyo Metropolitan Government purchased from the industries the right to abstract the natural gas, and groundwater pumping in the area was dramatically reduced. The second difference was the constraints of available water resources. Because there was not enough water available as source for the IWSW water supply, it took time to provide water from IWSW that the industries could rely on both in quantity and quality. At first IWSW in Tokyo used reclaimed water, and clogging and other problems occurred and hindered the provision of a stable water supply. Therefore, it took more time to reduce groundwater abstraction by industry than in Osaka. Rather than the provision of alternative water from IWSW, the promotion of the rational use of water, focused on groundwater, was effective. By imposing the obligation of reduction of groundwater use according to the Governor's recommendations, Tokyo Metropolitan Government tried to mitigate excessive groundwater abstraction. The recommendations were issued based on a local ordinance entitled "Tokyo Metropolitan Pollution Control Ordinance" enacted in 1970, which requested that groundwater users report their groundwater pumping record by the ordinance and follow the rational groundwater use plan designated by the Governor. Guidance from the Metropolitan Government was given to the industries that were requested to follow the official request of reduction based on the local ordinance.

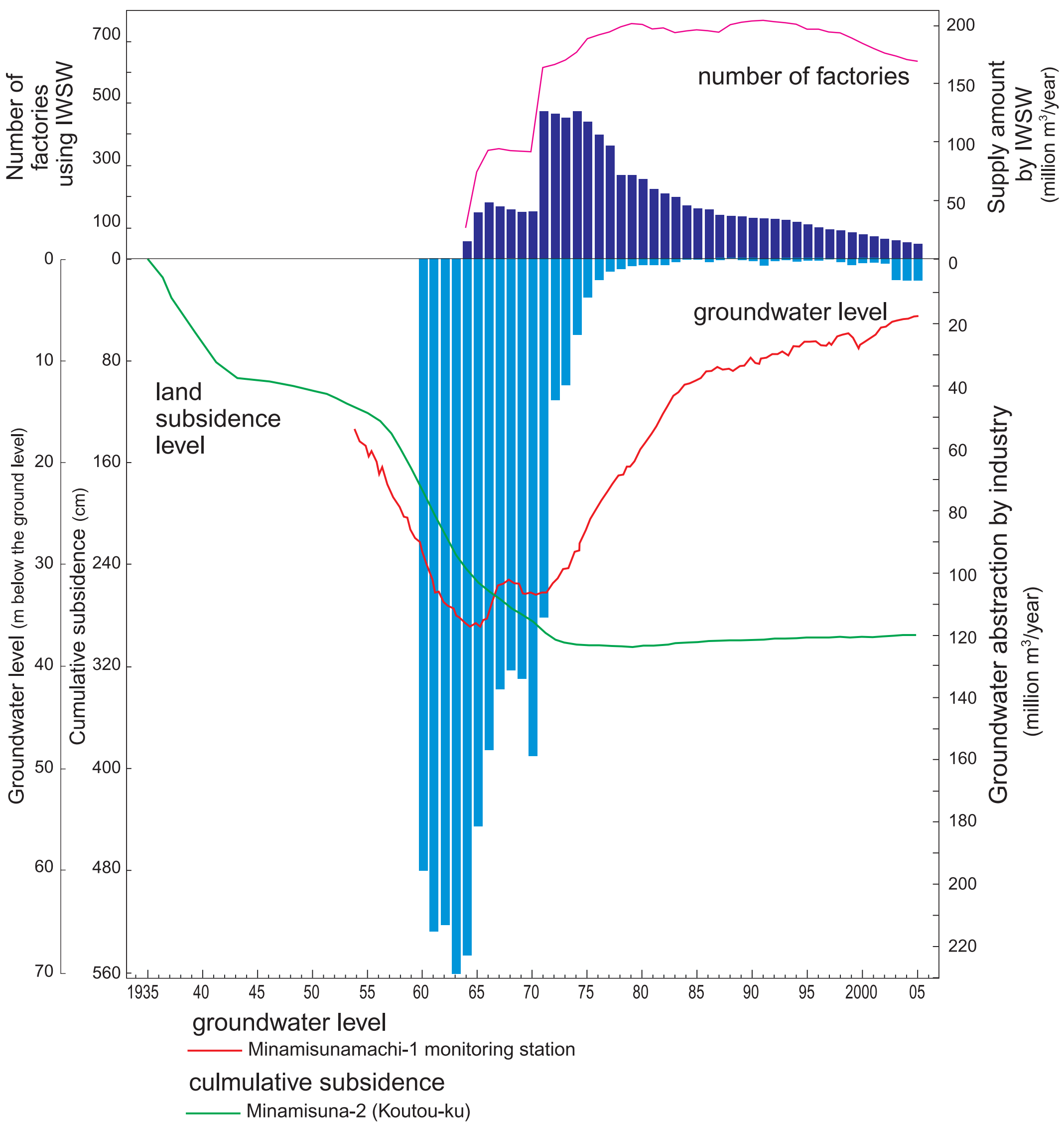


Figure 8. Shift from Groundwater to Industrial Water Works for Water Supply (Case of Eight Wards in Tokyo)

Note: Eight wards include Sumida, Koutou, Arakawa, Edogawa, Adachi, Kita, Itabashi, Katsushika.

(3) Both in Osaka and Tokyo, intensive groundwater use was mitigated by control of the major groundwater users. As a result, the groundwater level has been recovering (figure 5 for Osaka). However, the strict pumping control now poses an "enough groundwater" problem. The increase of the groundwater level has caused uplifting of building foundations and other problems to the urban infrastructure. Groundwater abstraction by a pumping facility which is outside the control by national laws or local regulations has been increasing for commercial purposes, and became highlighted as one of the reasons for the decline of the public water supply in recent years. The rational use of groundwater in which groundwater is used without causing environmental impact is now being discussed in Japan.

(4) In Tianjin, inter-basin water transfer was a major contributing factor in the reduction of groundwater use, especially in urban areas, in conjunction with the implementation of groundwater use control regulations (figure 9). Desalination of sea water and reclaimed water is promoted in the water stressed city, and it could contribute to reduction of groundwater use in coastal industrial areas. Water recycling was promoted in industrial sectors of urban area up to the rate of 75% in 1990s, and it also contributed to reduction of groundwater use (World Bank 1998). In the developing areas of the city, reclaimed water use from domestic sources has been promoted. Since 1986 a groundwater charge has been imposed, but because the charge is not higher than for other sources, it is not an effective driving force to make groundwater users switch to other sources of water. On the other hand, agricultural use of groundwater, which is the major beneficial use of groundwater, is not regulated by pumping regulations, nor are any charges imposed for doing so.

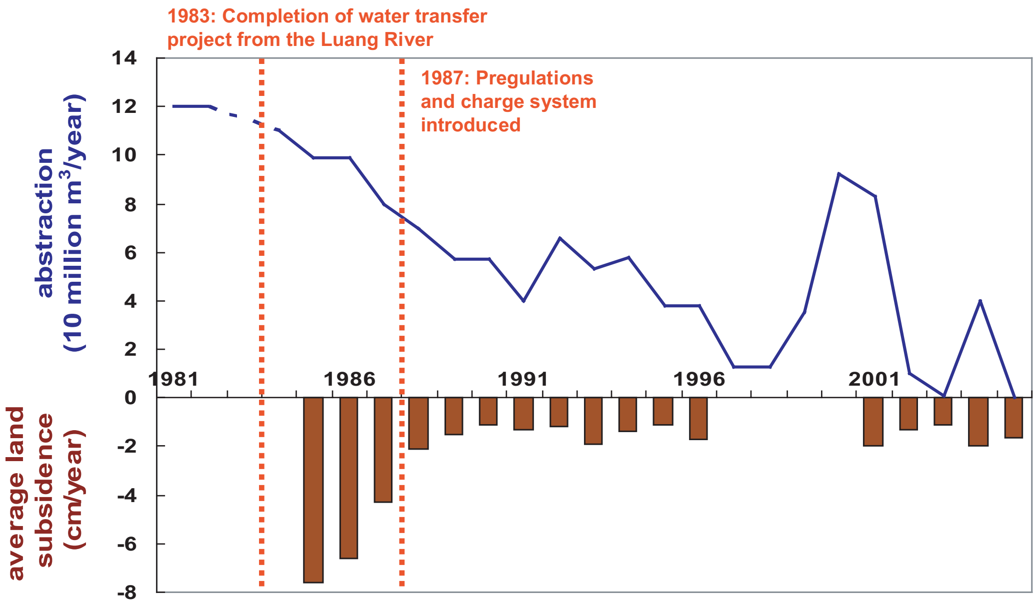


Figure 9. Groundwater Abstraction and Land Subsidence in Urban District in Tianjin

(5) The Groundwater Act of 1977 is the basis of groundwater management in Thailand, and since it was enacted, Bangkok has been struggling to control groundwater. In addition to limiting groundwater use with a licensing system, since the mid-1980s the minimization of groundwater abstraction for public water supply has been attempted. It is only recently that the minimisation plan has been attained. A groundwater charge was introduced also in mid-1980s, but the charge was lower than for the public water supply at that time. However, the increase in capacity of the public water supply scheme in conjunction with the increase in groundwater charges has recently been seen to be effective. A concern posed by industries regarding the public water supply is "the reliability of provided water" in terms of quality and quantity. Further promoting the shift from groundwater use to piped water supply is one of the issues to be considered.

(6) The key to sustainability of groundwater resources in Bandung is determining how to control groundwater use by the industrial sector. There are a set of measures to control groundwater use, but the implementation is not effective yet because of insufficiency of other water resources as alternatives to groundwater use. A groundwater tax has

been imposed, but it is cheaper than the public water supply and has therefore failed to send groundwater users a signal on the reduction of abstraction or to cause a shift from groundwater use to other water resources. Considering the competing demands of different sectors over the limited water resources available, wastewater recycling is a promising option as an alternative to industrial groundwater use. There is a local government program to encourage water recycling practices in industries, but there are no incentive mechanisms, not even financial support, to motivate industries to promote wastewater recycling.

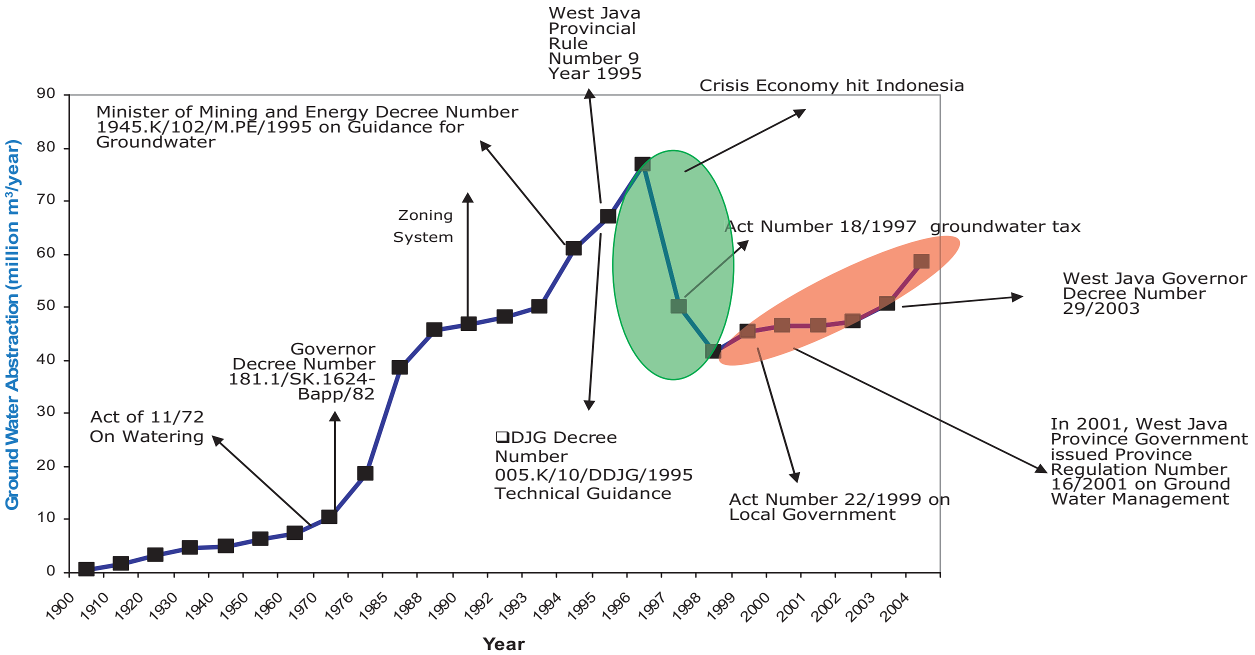


Figure 10. Deep Groundwater Use and Measures Taken in Bandung

(7) There are no specific control measures of groundwater use in Ho Chi Minh City. However, control measures including pumping regulations and a charging system have been prepared. In addition, the strategy on water resource management 2001-2010 issued by the Department of Natural Resource and Environment of the city includes reaching the target of keeping groundwater abstraction below 500,000m^3/day by 2010 to conserve groundwater.

(8) In Colombo/Kandy, where the threat to groundwater is less recognised, there are no control measures. Decentralised domestic use is dominant in the cities, and therefore the administrative cost is high for operating the management scheme, including the charging system. On the other hand, because the availability of groundwater is very limited in the cities, it is preferable to limit the crevice groundwater source only for rural or small-scale water project and to introduce a registration or licensing system for larger users. Regarding the future introduction of regulations, the matter of ownership of groundwater is expected to be a controversial issue.

3.3 Review of Management Measures

(1) Groundwater management is not adequately integrated with other areas of water management, such as surface water and rationalisation of water use. Data and information on water resources is also not well organised in a comprehensive way.

(2) Regulations to groundwater abstraction were introduced in Bangkok, Tianjin, Bandung, and Osaka/Tokyo, and are now under consideration in Ho Chi Minh City. Among these cities, only Japanese cities do not have comprehensive groundwater laws, while they do have laws regarding abstraction for specific beneficial uses. In addition to national laws, local regulations have been introduced to Tianjin, Bandung, and Osaka/Tokyo, but there is only a national law

for Bangkok. In the case of Japanese cities, local regulations have provisions that reflect specific local conditions and needs.

(3) In Bangkok, groundwater deeper than 15m below the surface is regulated by the Groundwater Law. In Osaka/Tokyo, groundwater abstraction is controlled based on the pump size (dimension and/or pumping capacity) or abstraction volume per day. Abstraction which is not covered by the regulations in these cities is regarded to be monitored or regulated to prevent future problems, as well as to keep equity to the access to water resources.

(4) Institutional arrangement of groundwater management varies from city to city. Except in Bangkok, local governments are in charge of the management. It is pointed out that there are several different organisations/sections which are responsible for different aspects of groundwater management, and that more coordination is necessary for effective implementation, especially institutional coordination of the control of groundwater use by different sectors (agriculture, industries and industries) as well as coordination of other water sectors (such as groundwater, surface water, and reclaimed water).

(5) Economic instruments to control groundwater use have been introduced in Bangkok, Bandung and Tianjin. In Bangkok, the "groundwater preservation charge," an additional charging scheme in addition to regular groundwater use charge, was introduced. The preservation charge is used only for groundwater conservation purposes. By introduction of the preservation charge, groundwater users with access to the public water supply should pay more for groundwater than for the piped water supply. The change in groundwater charges is expected to promote the shift from groundwater use to the public water supply.

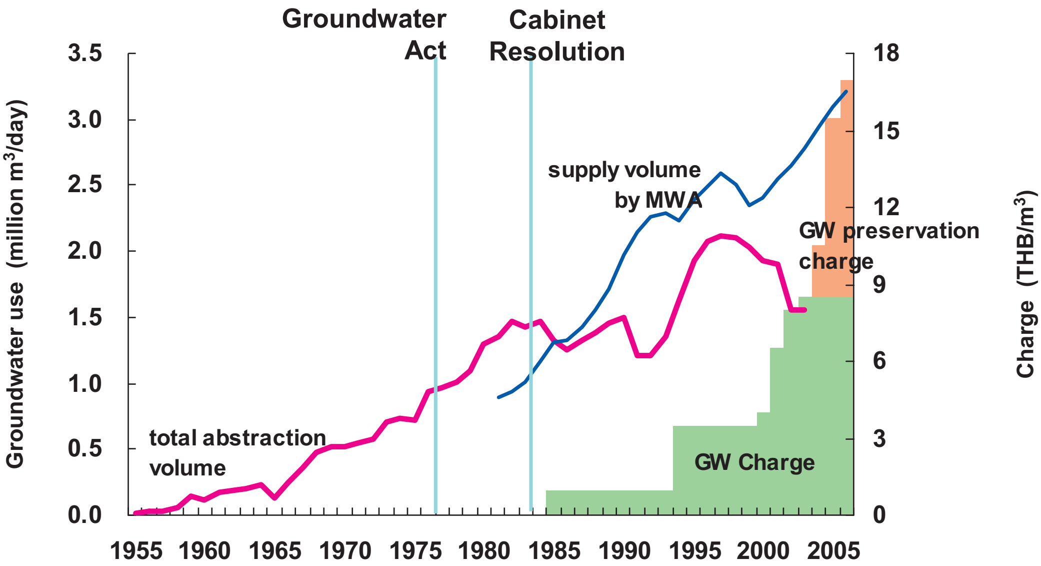


Figure 11. Groundwater Use Charge and Groundwater Abstraction in Bangkok

Note: GW means Groundwater

(6) In Bandung and Tianjin, groundwater is cheaper than the public water supply, and therefore there is no incentive for groundwater users to shift to the public water supply as a water resource. In Tianjin, the agricultural sector, which is the largest user of groundwater, is exempted from the groundwater charge.

(7) Regionally differentiated charging schemes are introduced according to specific local elements, such as the magnitude of the impact of intensive groundwater use, availability of other water resources that can substitute for groundwater use, and scarcity of the resources. In cities such as Bangkok, where regional concentration of groundwater use causes environmental problems such as land subsidence, while the overall stress on groundwater is relatively low, at the rate of 28.1 percent, a regional differentiation structure in charging scheme reflecting the different environmental cost and resource cost can induce efficient (differentiated) demand in each region.

(8) Although Bandung's charging system is not yet successful, the calculation system of water charges is sophisticated. The groundwater tax rate is calculated based on given values for three types of index. Those are: the natural resource component (water abstraction zone, water quality, availability of alternative water resources, and type of groundwater); the Recovery compensation component (use and abstraction volume); and the Raw water price (fixed amount/m^3). The groundwater tax is an abstraction volume-based, sophisticated tax structure concerning regional difference (water abstraction zone), and value of water resource for use (water quality).

(9) Regulations for groundwater abstraction can not be effective without other water sources as alternatives to groundwater use, simply because there would be no other way for water users to obtain water than from groundwater. Surface water supply through public water supply scheme is often the first alternative among other resources. However, in many cases, limited availability of surface water resources becomes a barrier in supply of surface water. In Tianjin and Bangkok it was necessary to find water sources from other basins. Pollution of surface water is also a concern in Ho Chi Minh City, Bandung, Bangkok, and Tianjin. The cost of development and supply of surface water is also a major constraint. The delay or insufficiency of water supply to substitute the groundwater source resulted in aggravation of the depletion of groundwater, as seen in Tokyo, Bangkok and Bandung.

(10) In Tianjin, where water resources are very scarce, reclamation of domestic wastewater has been promoted. Reclaimed water standards were set up for different uses. Currently a pilot project is now under implementation, and treated wastewater is further treated at the reclaimed water plants. The use of reclaimed water is for domestic non-potable purposes and industrial purposes, and different treatment technologies are introduced according to the purpose. A report by the Price Bureau of Tianjin said that the cost of reclaimed water was ranged from 1.10 CNY/m^3 for domestic use to 1.30 CNY/m^3 for industrial use, and that the price is lower than the cost to make water in public water supply (2.90 CNY/m^3) and water from the South-North Water Transfer Project (5 - 6 CNY/m^3). However, the current price of reclaimed water in the pilot project (1.30 CNY/m^3) is lower than both the public water supply (1.0 CNY/m^3) and the groundwater charge (0.5 CNY/m^3). Also, a 17% value added tax is imposed to the reclaimed water charge, while the tax for the public water supply is discounted to 6%. The distortion of the price should be reconsidered and adjusted for the promotion of use of reclaimed domestic wastewater.

(11) Wastewater reuse and recycling is a promising option for rationalizing industrial use of water, including groundwater. In Osaka City, many industries had to introduce wastewater treatment equipment in the 1970s to comply with water pollution control laws and regulations. In addition, a wastewater treatment fee was imposed, the amount of which was determined according to the amount of water that industries purchased from public water supply or industrial water supply works. As a result, water recycling became an option to minimize water use that could save money to buy, treat, and discharge water. In Thailand, water use efficiency in industry was noted in the National Water Strategies issued by the Water Resources Association of Thailand, but current water reuse and recycling is practiced with a view to minimization of waste. There is no specific legislation to promote reuse and recycling of water from the perspective of efficient use of water resources.

(12) In Ho Chi Minh City, surface water (Dong Nai River and Saigon River) is a prioritized alternative water resource for groundwater because not only is the potential capacity of surface water more than twice that of groundwater, but also only 16% of the available volume is being used so far. However, the quality of surface water has deteriorated in recent years. For example, the total nitrogen level of Dong Nai river, the main river used for tapped water, was 0.85 (mg/l) in 2000, but was 1.60 (mg/l) in 2004. The water quality deterioration of surface water leads to high cost of purification or the shift from using the water for drinking to using it for other purposes. In addition, the level of coliforms in surface water is higher than in groundwater, especially in deep aquifers. It indicates that surface water is more easily polluted by domestic waste water than groundwater. Therefore, the availability of surface water for domestic use in Ho Chi Minh City will be decreased if there is no pollution control.

(13) In terms of quality, to some extent, each city has standards for the conservation of groundwater and its use. China, Thailand, and Vietnam especially have specific environmental quality standards to conserve groundwater. In addition, all countries establish water quality standards for drinking purposes. However, groundwater quality monitoring is not systematically and adequately conducted and the result of the monitoring is also not well organised to assess the status of groundwater quality and compliance of quality standards. In Bandung, Colombo

and Kandy, periodical groundwater quality monitoring is not implemented. In Tianjin, Bangkok and HCMC, not all items which are regulated by environmental standards for groundwater are monitored, even though they have conducted periodical groundwater quality monitoring.

Table 8. The Status of Groundwater Quality Monitoring

City	Frequency	Responsibility	Number of Station
Tianjin	Periodical	Tianjin Environmental Monitoring Centre	unknown
Bandung	Temporary	DGTL	100stations (1991) 35stations (2000)
Colombo/Kandy	Temporary	-	-
Bangkok	Periodical (1-3 times/year)	Department of Mineral Resources	117stations (304 wells)
HCMC	Periodical (1-4 times/year)	Department of Natural Resource and Environment	40stations (86 wells)
Osaka	Periodical (1 time/year)	Ministry of the Environment/Osaka City and Prefecture government	83 stations
Tokyo	Periodical (1 time/year)	Ministry of the Environment/Tokyo Metropolitan government	268 stations

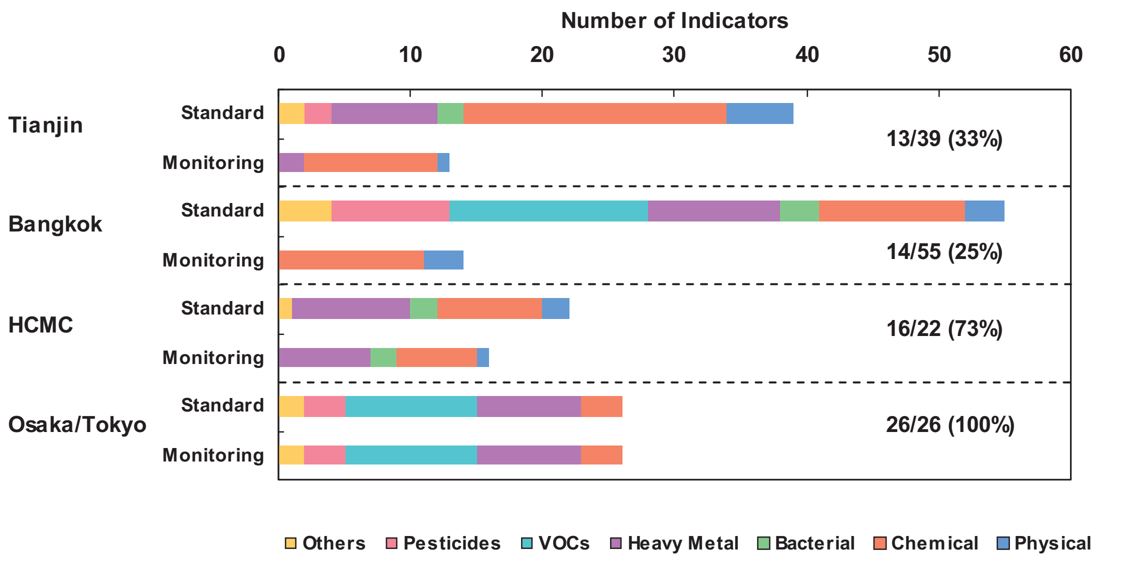


Figure 12. Number of Indicators Tested at the Regular Groundwater Quality Monitoring and Designed in the Groundwater Quality Standard

(14) The situation of the treatment of domestic and industrial waste water, and of hazardous solid waste is poor and poses a threat to the groundwater. Although in the case study cities, fertilizer and pesticides are consumed in agricultural activity, regulation of the consumption can not be systematically implemented. Additionally, due to urbanization, rapid industrialization, and intensive agriculture, not only the volume of pollutants is being increased, but also the diversity of contamination needs to be considered in the future.

CHAPTER 1

CHAPTER 2

CHAPTER 3

4. Conclusion

i. In cities, groundwater resources are very useful and important in sustaining people's lives. However, the intensive use of groundwater has depleted this resource and also caused problems such as land subsidence. On the other hand, as seen in Japanese cities, strict control of groundwater pumping resulted in the increase of groundwater level and has now created "enough groundwater" problems. Merely placing restrictions on the abstraction of groundwater does not contribute to the "sustainable" use of groundwater where it is used without causing critical depletion of the resources.

ii. In many cities with seasonal fluctuations in water availability, the overall condition of water resources is very grave. As a stable source of water as well as a way to rationalise water use, reclaimed water can be promoted as a promising option and an alternative to groundwater. Especially in the cities where industrial groundwater use is dominant, such as Bangkok, Bandung, and Ho Chi Minh City, the "reclaimed water use" industrial sector has significant potential to reduce groundwater stress. Moreover, reclaimed water use also contributes to pollution control.

iii. When properly applied, economic incentives/disincentives, such as charging for groundwater, are effective tools for groundwater management. The systems of charges work well, particularly in the industrial sector, because industries are sensitive to increases in the cost of water in their production processes. In addition to direct charges, indirect charges, especially wastewater discharge/treatment charges, can also contribute to the reduction in groundwater abstraction. However, these charging systems can not work well without appropriate price-setting.

iv. Land use change is pointed out as affecting the recharging capacity. In Bandung, the recharging capacity has decreased due to urbanisation. Land use change also has significant effects on water quality beneath the ground. Therefore, from the aspect of quantity and quality, land use plans are important for groundwater management. However, the impact on groundwater is not well considered at the design stage of land use plans.

v. In countries where groundwater use rights are not clearly defined by law, it is difficult for the government to take proactive measures in groundwater management. On the other hand, governmental control over groundwater abstraction does not always contribute to conservation of the resources. In the Bandung's case, some municipal governments issued more groundwater abstraction permits in order to obtain more revenue after they were authorised to give permits. This resulted in the acceleration of groundwater pumping, even though the permission system had been introduced to promote adequate use of groundwater.

vi. In terms of groundwater quantity control, many cities have already introduced basic measures. However, the implementation stage varies according to factors such as the adequacy of regulatory schemes for the major groundwater users, availability of other water sources that could be substituted for groundwater use, and incentive mechanisms designed to shift groundwater use to other water resources. Groundwater quality management should be strengthened with adequate monitoring put in place.

vii. In addition to the pollution caused by traditional pollutants, new types of groundwater pollution caused by pollutants such as VOCs and pesticides might become even more serious in the near future. So far, however, neither substantial measures nor periodical monitoring have been put in place.

viii. In many countries, surface water is a potential alternative water resource to groundwater. However, discussion on the availability of both water resources is not conducted from the aspect of their quantity and quality.

ix. Although there is a certain mount of data on groundwater levels in many cities, scientific facts such as the existence of groundwater, groundwater use, and groundwater quality are either insufficient or poorly stored. This hinders effective planning and implementation.

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