Sustainable Groundwater Management in Asian Cities

a summary report of Research on Sustainable Water Management in Asia

Freshwater Resources Management Project
Institute for Global Environmental Strategies

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Preface

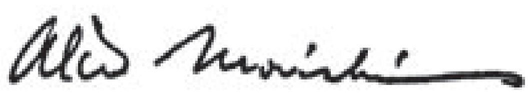
Groundwater is a fundamental and precious resource, providing reliable, good-quality and low-cost water for domestic, industrial and agricultural purposes. Many Asian cities depend on groundwater for sustenance and take advantage of the resource to facilitate economic activity. The rapid industrialization and urbanization taking place in Asian cities, however, have intensified the stress placed on this precious resource. In response to the growing demand for water, groundwater has been depleted due to excessive abstraction, and resultant land subsidence has been observed in some cities. Aquifer contamination with various types of pollutants is also a serious concern. Appropriate policy measures are urgently required to cope with the emerging problems and to manage groundwater in a sustainable manner.

With the significance of sound groundwater management in Asian cities in mind, the Freshwater Resources Management Project, led by Prof. Shinichiro Ohgaki, at the Institute for Global Environmental Strategies placed immediate research focus on groundwater management, particularly in the urban and peri-urban areas of Asian cities. Our research is intended to formulate better policy options for sustainable water management, taking into account the socio-economic and physical conditions. To facilitate our research and produce practical recommendations, case studies were carried out in Bangkok, Thailand; Ho Chi Minh City, Vietnam; Bandung, Indonesia; Tianjin, China; Colombo and Kandy, Sri Lanka; and Osaka, Japan.

The report entitled "Sustainable Groundwater Management in Asian Cities" is a summary of our research for these two years. This report consists of three main parts: 1) Recommendations for Sustainable Groundwater Management in Asian Cities, 2) Situation Analysis and 3) Summary of Case Studies. The first part highlights the recommendations for better groundwater management. The recommendations included were designed to address the most critical and timely problems associated with groundwater, which are now being observed in the rapidly industrializing and urbanizing Asian cities. The recommendations target various stakeholders, such as policymakers, who are involved in groundwater management. The second part, Situation Analysis summarises the background information of groundwater resources and its management in the cities where the case studies were conducted. This constitutes the basis of our recommendations. The third part compiles summaries of each case study conducted, which gives readers more detailed information of the groundwater management and recommended actions to improve current challenges in each of the case study cities.

Finally, I would like to offer my sincere gratitude to the research partners who directed the case studies in each country for their contribution to the research. It is my sincere wish that this report will help Asian cities pursue a sustainable path for groundwater use, thereby contributing to sustainable development.

March 2006



Akio Morishima
Chair of the Board of Directors, President,
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List of Abbreviations

ADA	Agricultural Development Authority, Sri Lanka
AWLR	Automatic Water Table Recorder
Bt	Thai Baht
COD	Chemical Oxygen Demand
DARD	Department of Agriculture and Rural Development, Viet Nam
MARD	Ministry of Agriculture and Rural Development, Viet Nam
DGR	Department of Groundwater Resources, Thailand
DI	Department of Industry, Vietnam
DONRE	Department of Natural Resource and Environment
DOSTE	Department of Science, Technology and Environment
DTPW	Department of Transportation and Public Works, Viet Nam
EC	Electric Conductivity
EIA	Environmental Impact Assessment
GDF	Groundwater Development Fund
GDP	Gross Domestic Product
GPP	Gross Provincial Product
GPS	Global Positioning System
GW	Groundwater
HCMC	Ho Chi Minh City
IWMI	International Water Management Institute, Sri Lanka
IWSW	Industrial Water Supply Works
MI	Ministry of Industry, Thailand
MONRE	Ministry of Natural Resources and Environment, Thailand/Viet Nam
MWA	Metropolitan Water Works Authority, Thailand
NCWR	National Water Resources Council
NEB	National Environment Board, Thailand
NGO	Non-governmental Organisation
NPA	
NWS & DB	National Water Supply and Drainage Board
OMWRM	Office of Minerals and Water Resources Management
PC	People's Committee, Viet Nam
PDAM	Regional Water Company, Indonesia
PWA	Provincial Waterworks Authority, Thailand
RGDP	Regional Gross Domestic Product
RID	Royal Irrigation Department, Thailand
Rp	Indonesian Rupiah
RTSD	Royal Thai Survey Department
SEA	Strategic Environmental Assessment
UNICEF	United Nations Eductional, Scientific and Cultural Organisation
WHO	World Health Organisation
WRB	Water Resources Board, Sri Lanka
WSE	Water Supply Enterprise

[Symbols]

μ	Micro
Ag	Silver
Al	Aluminum
As	Arsenic
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
F	Fluorine
Fe	Iron
Hg	Mercury
Mn	Manganese
Ni	Nickel
P	Phosphorous
Pb	Lead
Se	Selenium
Zn	Zinc

Editorial Notes

The name of the city and what we called "case study cities" described in the report do not necessarily correspond with the administrative boundary of the respective cities. The following is the description of the actual coverage area of each case study city.

[Coverage area of each case study city]

Bangkok (2,844 km^2):	7 Provinces namely, Bangkok, Nonthaburi, Samut Prakan, Pathumthani, Samut Sakhon, Nakhon Pathom, and Ayutthaya
Ho Chi Minh (2,095 km^2):	Ho Chi Minh City
Bandung (2,341 km^2):	Bandung Basin which includes a part of Bandung regency, Sumedang regency, Bandung city and Cimahi city
Tianjin (11,919 km^2):	Tianjin municipality
Colombo (1,575 km^2):	Twenty one divisional secretariat divisions*, namely Aththanagalla, Biyagama, Colombo, Divulapitiya, Dompe, Gampaha, Hanwella, Homagama, Ja Ela, Kaduwela, Katana, Kelanlya, Kollonnawa, Negombo, Mahara, Maharagama, Minuwangoda, Meerigama, Padukka, Wattala, and Sri Jayawardanapura Kotte
Kandy (322 km^2):	Five divisional secretariat divisions*, namely Gangawata Korale, Harispattuwa, Kundasale, Udunuwara, and Yatinuwara
Osaka (222 km^2):	Osaka city

** Sri Lanka has nine provinces which are subdivided into districts. The districts are further divided into the divisional secretariat areas.*

It should be also noted that there was a limitation in data availability and reliability in the case studies, although all the efforts have been made to obtain necessary and the most reliable data, and to appropriately interpret the data into the analysis conducted.



PART I

RECOMMENDATIONS FOR SUSTAINABLE GROUNDWATER MANAGEMENT IN ASIAN CITIES

Groundwater management in Asian cities should be dynamic and proactive, considering not only the diversity of hydro-geological conditions but also the policy environment that keeps changing in the course of continuous urbanization and industrial development in Asian cities.

Groundwater is a reliable resource for drinking and production both in terms of quantity and quality. However, the resource is now under severe stress in some Asian cities because of the excessive groundwater abstraction in the course of socioeconomic development. Problems such as water table drawdown, decreasing well yield, land subsidence, and salinity intrusion that have emerged as the results of overexploitation of groundwater may incur socioeconomic losses and disturb the development of the cities that face the problems. These problems are either irreversible in nature or require extended periods to abate. Therefore, we need to consider how we can conserve this precious resource while taking full advantage of it for the development of Asia.

The overexploitation of groundwater has already created problems in cities such as Tianjin (China), Bandung (Indonesia) and Bangkok (Thailand). Although groundwater problems are not well recognized, a city experiencing rapid population and economic growth such as Ho Chi Minh City (Viet Nam) may depend more on groundwater to meet the growing demand for water, and experience subsequent problems with the groundwater. In the case of Colombo and Kandy (Sri Lanka), the groundwater has not been fully utilized. However, it has the potential of playing a supplemental role as the demand for water increases.

The following recommendations were created with the intention of highlighting promising or important elements for better groundwater management in the growing Asian cities. The recommendations are based on our empirical studies on groundwater in some Asian countries that have differing socioeconomic status: Tianjin (China), Bandung (Indonesia), Colombo and Kandy (Sri Lanka), Bangkok (Thailand), Ho Chi Minh City (Viet Nam), and Osaka (Japan). The recommendations consist of three parts, namely General Recommendations (from 1-1 to 1-4), Recommendations for Respective Beneficial Uses (from 2-1 to 2-7), and Recommendations for Overcoming Barriers to Implemtation (from 3-1 to 3-3). Some boxes are attached to provide the further infomation relevant to the recommendations.

Groundwater management should be implemented in accordance with the local hydro-geological, social, economic and cultural conditions. Therefore, our recommendations may not be universally applicable. Instead, they should be interpreted and optimized according to local contexts.

1. General Recommendations

1-1. The optimal combination of different policy measures can maximize the effectiveness of groundwater management. The review and adjustment of existing policy measures is crucial in meeting the changes in the socio-economic and environmental background of the respective cities.

The review of groundwater management of seven Asian cities shows that there are four major elements in groundwater management. They are: (a) regulation governing groundwater abstraction, (b) provision of economic incentives/disincentives to reduce groundwater abstraction (e.g. charges for groundwater usage and wastewater discharge), (c) provision of alternative water resources to groundwater, and (d) support for the major groundwater users in their water-saving activities (table I-1). **Successful groundwater management is a function of how optimally the different policy measures are integrated according to the local situations**.

It is also important that **groundwater management should be regularly reviewed and updated to meet the policy needs that can change over time**. In the case of Bangkok, the Groundwater Act was revised twice and strengthened to further regulate groundwater to meet the expansion of the city. In some Japanese cities, such as Osaka, regulations on groundwater abstraction enacted nearly a half century ago now need to be reviewed and updated to cope with emerging problems such as the excessive increase in the groundwater level.

1-2. Groundwater conservation should be an integral part of urban planning.

Urbanization is a typical phenomenon observed throughout the Asian region, and the accompanying land usage changes can alter the natural setting of the area in many ways. Water resources are heavily exploited and the land surface is completely disturbed and changed into either denuded, cultivated or paved areas. These changes reduce the area available to replenish the groundwater, thereby increasing and accelerating surface runoff. In addition, the increased demand for water as the city expands often draws attention to groundwater as a useful resource and often results in excessive abstraction as we observed in the case of Bandung.

To avoid this situation, **urban planning should incorporate measures to conserve groundwater**. The following factors may be considered:

- The establishment or protection of replenishing zones to retain the capacity for replenishing the groundwater;
- The introduction of decentralized recharge schemes in household or community areas such as backyard

Table I-1. Measures Taken in Selected Cities

measures / city	(a) Regulations governing groundwater abstraction	(b) Economic incentives/ disincentives to reduce groundwater abstraction	(c) Provision of alternative water resources	(d) Support for water saving activities
Bangkok	National law (to regulate all sectors in principle)	User charge and groundwater preservation charge	Surface water (by public water supply scheme)	No specific measures
Bandung	Local law (to regulate all sectors in principle)	User tax	Expansion to include surface water usage being considered	No specific measures
Tianjin	Local level (to regulate all sectors except agricultural use)	User charge	Surface water transfer from other basins	Water conservation policy for industries
Osaka	National laws (industrial and commercial-scale uses in control area)	No user charge, but wastewater treatment charge applies.	Surface water to industrial sector (by new water supply scheme for industries)	Financial support for the introduction of water-saving technologies

rainwater tanks;
- The installation of water-saving technology stipulated in the building code (e.g. recycled water for flushing toilets).

Such attempts have already been introduced in Japan, Western Australia and Chennai in India. Sri Lanka recently introduced a rainwater harvesting policy which mandates that all new large establishments should have rainwater harvesting facilities. As another step, they are planning to restrict the use of tap water in activities such as washing cars and gardening.

1-3. Groundwater management should be designed within the framework of a holistic urban water management policy.

It is a well-established fact that both groundwater and surface water are interlinked and have an interdependent relationship through the water cycle. Therefore, **it is essential to look at these two water sources more holistically rather than individually**. This approach not only optimizes management costs but is also very useful in minimizing risks during extreme situations such as droughts or incidents of contamination.

In many Asian cities including Tianjin, Bandung, Colombo and Ho Chi Minh City, surface water is highly contaminated as a result of the improper discharge of untreated wastewater and solid wastes from households and industry. Therefore, **surface water quality control should be further promoted in the context of preventing potential pollution to groundwater in Asian cities**.

1-4. Groundwater abstraction rights should be assigned to the government sector in statutory form to enable effective groundwater control.

Groundwater abstraction rights should be stipulated in a statutory form and a public entity (in principle, the national government) should be entitled to have overall responsibility of groundwater management for the effective control of groundwater abstraction.

In countries such as Japan and Sri Lanka where the groundwater use rights are not clearly defined by law, it is difficult for governments to take proactive responses to groundwater management, including the allocation of groundwater usage rights by the government and groundwater charges. Therefore, the **right to control groundwater resources should be assigned to governments** by law to ensure the effective allocation of groundwater resources to the respective beneficial applications.

On the other hand, the case of Bandung showed that a municipal government made available more groundwater abstraction permissions to generate more revenue, and this resulted in accelerated groundwater pumping. This indicates that government control over groundwater abstraction does not always contribute to conservation of the resources. To prevent this abuse of governmental responsibility, **a panel of different stakeholders including experts and groundwater users should be established to regularly monitor the groundwater management policy**.

2. Recommendations for Respective Beneficial Uses

For the Industrial Sector

Industry is a major user of groundwater in Asian cities and it consumes a huge amount of water. The trend in industrial activities is a big factor in changes in water demand. This was evident in Bandung, where groundwater abstraction had dramatically dropped in 1997 because many industries stopped or scale down production as a result of the Asian economic crisis. Therefore, the control of groundwater use by the industrial sector is the key to groundwater management in Asian cities.

2-1. Available government resources should be allocated more to water reuse and recycling in industry.

The encouragement of water conservation practices in industry is very effective both in controlling groundwater abstraction and in the conservation of available water resources, as the experience in Osaka shows.

Therefore, **governments should put the priority of their policies on encouraging the efforts of industry to conserve water and allocate more resources, both finance and human resources, for that purpose**. For example, groundwater control regulations should be implemented with the provision of technical guidance and modest financial support for the introduction of water-saving technologies. Improving water pollution control measures, such as enforcing effluent standards, can also encourage industry to minimize its water inputs to reduce the volume of wastewater.

The purpose and amount of groundwater usage differs according to the type of industry. Therefore, **it is also necessary to consider all types of industry to determine what types should be given priority**. For example, rather strict regulations governing groundwater usage can be introduced in combination with measures to promote the introduction of water-saving technologies to an industry, such as the steel industry, which uses a lot of water but can recycle wastewater within its production process. But for an industry that needs rather good-quality water and cannot recycle or reuse it in its production process, such as the food industry, the same combination of policy measures as those that apply to the steel industry cannot work well.

2-2. Groundwater usage charges, wastewater treatment charges and other economic disincentives for groundwater usage can effectively control the demand for groundwater.

Charging for groundwater usage can be an effective tool when properly applied as the experience of Bangkok and Bandung shows. In particular for the industrial sector, the system of charges work well because industries are more sensitive to increases in the cost of water in their production process. Bangkok's rapid increase in charges for the use of groundwater illustrates the effectiveness of a charging scheme to discourage groundwater abstraction (Box I-1). In addition to direct user charges, **indirect charges especially wastewater discharge/treatment charges can contribute to the reduction in groundwater abstraction**, as well. Hiratsuka City in Japan managed to halve the volume of industrial groundwater pumping from 1972 to 1976 by rationalizing water usage (Shibazaki 1981). An analysis concluded that the introduction of a wastewater treatment charge motivated industry further to rationalize its water usage. It was estimated that the wastewater treatment charge was 28 - 56 yen (0.24-0.48 USD)/m^3, which was below the investment for water-saving technology, estimated about 19.5 yen (0.17 USD)/m^3.

Box I-1. Effectiveness of Groundwater User Charges

The Success of Bangkok and the Inefficiency of Bandung in Introducing the Charging System

In the Bangkok study area, groundwater charge rates rapidly increased from 3.5 Bt (0.09 USD)/m^3 to 8.5 (0.22 USD)Bt/m^3 from 2000 to 2003, and the number of private wells began to decrease after 2001 (figure I-1). In addition to groundwater charges, the Groundwater Preservation Charges were

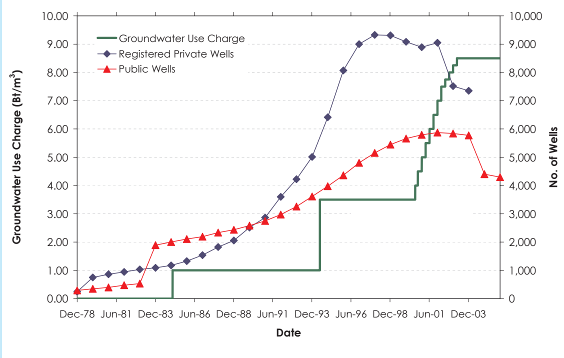

Figure I-1. Variations in Groundwater Usage Charges and Number of Private and Public Wells in Bangkok

introduced in 2004. The total amount of the two charges far exceeded the price of public water supply. Therefore, groundwater lost its attraction over surface water, particularly to industry, which consumes a large amount of water. On the other hand, in Bandung, groundwater tax were determined based on a calculation of the value of water which was stipulated by law. However, the groundwater charge ranged from about Rp 1,750 (0.19 USD) to Rp 3,138 (0.34 USD)/m^3, while the water tariff of public water supply was about Rp 2,725 (0.29 USD) to 9,600 (1.05 USD)/m^3 for industry. Because of the comparative strength of groundwater in terms of cost, industry continued to use groundwater although the level of the water table was decreasing. This indicates that the pricing of groundwater should be set at a price that is the same or higher than other sources of water if the groundwater charge intend to discourage groundwater usage. However, the affordability of the marginalized people, must be considered in price-set.

2-3. Governments should pay prior attention to groundwater pollution by Volatile Organic Compounds (VOCs) and take the necessary preventative measures.

In addition to heavy metals and toxic chemicals, contamination by substances known as Volatile Organic Compounds (VOCs), such as trichloroethylene and tetrachloroethylene, may emerge as the major pollutants in Asian cities in the course of industrial development. Trichloroethylene, for example, can be found in cleansing solvents used in such applications as metal and semi-conductor factories. With the possible development of related industries in Asia, the prevalence of aquifer contamination by the VOCs cannot be denied. Once aquifers and soils become contaminated with pollutants, it becomes difficult to remove the pollutants considering the available technologies and required cost, making it all the more important to take preventive measures. Environmental standards and the monitoring of suspected pollution sources should be introduced by the governments. The environmental or effluent standard targeted for these substances has not been set up in the cities in the case studies, except for Bangkok and Osaka.

Establishment of records and reporting system to promote voluntary improvements in business in the management of such chemicals, the so-called Pollutant Release and Transfer Register (PRTR) systems, is also an option to effectively manage the substances.

For the Domestic and Commercial Sectors

A substantial number of people living in Asian cities depend on groundwater as a source of drinking water. Municipal water supply in Bandung still depends on groundwater to some extent because of the available surface water resources. In Ho Chi Minh City, groundwater is also used as an important source of municipal water supply. Because groundwater is a decentralized resource, it is difficult to monitor and regulate groundwater abstraction by individuals. It is believed that a large number of unregistered wells, especially those for domestic usage, constitute one of the challenges of groundwater management. In terms of quality, shallow groundwater, on which many people depend, has deteriorated because of improper sanitary conditions.

2-4. Groundwater abstraction by heavy users should be minimized first in places facing excessive groundwater abstraction associated with negative impacts on society.

In places where the negative impacts of overexploitation of groundwater is substantial, minimization of or a ban on abstraction by heavy groundwater users such as public water suppliers and commercial and business users should be implemented first. Such an abstraction regulation should be accompanied by other initiatives, such as the provision of other water sources including rainwater and recycled water for non-drinking purposes; the repairs of water leakage; and the provision of temporary financial support for water saving technologies.

On the other hand, the monitoring and control of individual groundwater abstraction at household level should be also improved, e.g. through a community groundwater management scheme.

2-5. Proper guidance on on-site wastewater treatment should be provided for conservation of groundwater quality and the reduction of health risks.

It is well recognized that urbanization affects both the quantity and quality of the underlying groundwater systems in many ways. This is particularly true when a city straddles a productive shallow aquifer that is subject to heavy use. Major groundwater withdrawals results in the lowering of the water table and this can often result in increased water leaking from the surrounding layers. If waste disposal in the area is poor, as often seen in developing countries, the groundwater resource can easily become contaminated.

Shallow aquifer contamination is becoming a serious problem, especially because of the poorly managed or constructed on-site sanitary systems. In the case of Ho Chi Minh City, the incidence of the installation of improper septic tanks, which are not appropriately covered by concrete, is considerably high in some districts. More than 70% of the domestic septic tanks in two districts are reported to be improperly constructed, which increases the risk of effluent leaking from the septic tanks to contaminate shallow aquifers. The present situation in many of the other cities such as Colombo, Kandy and Bandung is not significantly different. The shallow groundwater in these cities is

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often contaminated with coliforms.

One of the major causes of the shallow groundwater contamination is the lack of technical guidance in on-site sanitary systems. To control the quality of shallow aquifers in particular, the government should provide technical guidelines on construction and maintenance. In addition, awareness programs and technical training in maintenance should be given to the local people to enable them to follow the guidelines.

Box I-2.The Need for Proper Infrastructure Development

Safeguarding all water resources in the cities in the case study and as a whole within the Asia region as a whole is more critical mainly due to the limited coverage of proper piped water supply, and therefore a high percentage of people have to depend on alternative sources of water for their everyday needs. Among the area of the case study, most cities have very low water supply coverage (Bandung 20-50%, Colombo 44% and Kandy 39.5% with some areas less than 10%) forcing people to use shallow groundwater.

Many recent studies have shown that shallow groundwater contamination is very common, mainly due to poor wastewater management. Therefore, it is imperative to have proper sanitary disposal systems or domestic wastewater treatment plants accompanying the urbanization process. Moreover, the situation has been exacerbated by a number of factors. These include a lack of proper wastewater discharge standards. (In Sri Lanka, wastewater discharge standards do not include limits for nutrients.) Other factors are poor enforcement, such as Colombo, Kandy, Ho Chi Minh City, Bandung and Tianjin, and poor or nonexistent building regulations for onsite sanitary systems. Introducing strict standards will ensure the protection of the surface water resource as seepage from surface water bodies can contaminate the entire groundwater resource in the area. This is especially true in areas with heavily contaminated canal systems and rivers, such as Ho Chi Minh City, Bandung and Colombo.

For the Agricultural Sector

Urban sprawl is widespread in Asia. The conjunction of agricultural and urban areas is often observed in particular in peri-urban areas. Conflict over water, including groundwater, between the agricultural and urban sectors is recognized as an issue in Asian cities. Agriculture uses a substantial amount of water, and therefore the rationalization of the agricultural use of groundwater is a key in sustainability. Agricultural activities may have negative impacts on groundwater quality, and this has recently been observed in many Asian countries.

2-6. Groundwater use by the agricultural sector should be controlled to prevent possible environmental impact due to intensive exploitation.

In principle, groundwater use by all beneficiaries should be controlled to prevent the excessive abstraction of groundwater resource and its associated problems. However, groundwater abstraction control in the agricultural sector often remains insufficient. In particular, peri-urban areas, in the course of development, may be faced with conflicts in water demand between the agricultural sector and the growing domestic and industrial sectors. Therefore, the domestic and industrial sectors as well as the agricultural sector should be a target of groundwater management.

A registration and/or capping system of groundwater abstraction should be encouraged for the sector. In addition to such regulatory measures, support for the introduction of water conservation technology and expertise should also be promoted at the same time. This support includes financial assistance for the introduction of available technology to promote less-water intensive agricultural production.

Box I-3. Sri Lanka's Agrowell Program

The introduction of the latest irrigation techniques through subsidy schemes can improve the irrigation efficiency but require better planning for control of usage

The recently introduced subsidy program in Sri Lanka, the "Agrowell Program," encourages shallow groundwater irrigation to enable individual peasant farmers to irrigate their crops at their discretion and to diversify their activities.

Although the program has substantially improved the economic conditions of the local farmers, the rapid and uncontrolled diffusion of groundwater extraction and practices that include excessive irrigation and the overuse of fertilizers is presenting the risk of the shallow groundwater receding and of the groundwater becoming contaminated by excess nutrients. Therefore it is vital to raise the farmer' s awareness and introduce new technology to improve irrigation efficiency along with such programs to prevent these outcomes.

2-7. Fertilizer inputs should be capped to reduce the nitrate contamination of groundwater.

Nitrate and pesticide contamination in aquifers has been identified as a major problem in many Asian cities. For example, nitrate was the most frequently detected substance among the 18 chemicals in a national survey of groundwater quality conducted in Japan in 1982. Approximately ten percent of the 1360 samples exceeded 10 mg/l, the drinkable limit for nitrates in Japan. Rather high values of nitrates in aquifers have been detected in Bandung, Ho Chi Minh City, Colombo and Kandy.

Fertilizer use in agriculture in believed to be the main cause of nitrate contamination. The reason is that excessive nitrates in soil can leak into the groundwater, leading to nitrate contamination. More fertilizer tends to be used for more agricultural production to sustain an increasing population and generating more income. Measures should be taken in advance without much impact on the farmers. Capping the inputs of fertilizers is one alternative, as in the test case of Kakamigahara in Japan (Box I-4). In conjunction with the necessary technical improvements, a capping policy should be encouraged.

Box I-4. Reduction in the Use of Fertilizers Will Not Harm Agricultural Production

- A Field Survey in Kakamigahara, Japan -

Kakamigahara, Gifu Prefecture, Japan is known for its carrot production. In this city, most of the potable water comes from groundwater. However, the nitrate concentration of groundwater had been increasing since the 1970s, resulting in the damage for groundwater usage in this area. The overuse of fertilizers in agricultural activities was suspected as a cause for the high nitrate concentration, and thus better management of fertilizer use was a timely requirement. Field surveys conducted in the city revealed that reduction in the use of fertilizers by around 25 % from 400 kg-N/ha/y to 300 kg-N/ha/y was possible without harming the production and the quality of the carrots.

This is a good example of better fertilizer management, where an attempt is made to protect aquifers from nitrate contamination. It is critical for farmers to become aware that an appropriate amount of fertilizer should be consumed in the farming, avoiding the overuse of fertilizers. In this regard, public awareness is essential in promoting an appropriate volume of fertilizer use in farming.

(source) Hirata. T, 2000

3. Recommendations for Overcoming Barriers to Implementation

3-1. Scientific research and monitoring should be promoted by governments and research institutes to obtain reliable information for groundwater policy-making.

Reliable information is essential for effective policy-making and implementation. However, the groundwater resources in the cities in the case study are often poorly understood by both the decision-makers and the users of the groundwater. Even if there is available information, it is not well organized and not properly shared among relevant stakeholders. The poor situation concerning groundwater information makes groundwater management in the case study cities difficult.

Therefore, the monitoring of groundwater quality and quantity should be regularly conducted and properly organized so that the data can be readily used for policy-making. International cooperation in understanding the resources should be encouraged to improve the capacity of human resources to manage the knowledge.

Box I-5. Common Database, Funding for Research and International Cooperation for the Sustainability of the Groundwater Resources within National Boundaries

The existing monitoring programs are very limited, as is reliable information and research on the groundwater in cities in the case study. In all cases, the extent of available resources is poorly understood and in most cases, only approximate safe yields are available. With very few new research studies being initiated recently, the situation has become critical. For example, no programs for proper monitoring of groundwater quantity and related problems were seen except in Bangkok. Significantly, there was no monitoring of groundwater quality whatsoever in Bandung, Colombo or Kandy. Most of the available data within the cities is either incomplete or of doubtful reliability. Even the limited data is scattered making access and use difficult.

In terms of quality data, the situation is even worse. Neither city has given any priority to the monitoring of quality. Also, the

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influence of global issues, such as the far-reaching and increasingly severe effects of climate change, has not even been considered. This is particularly true in Colombo, one of the cities in the case study, which is facing surface water shortages from changes in rainfall patterns. The effects are being felt in the groundwater resources. The problems are felt in other cities, although the extent of the problem is unknown due to the lack of research.

These facts indicate that it is apparent that the available data is very limited within Asia and that negligible focus is given to research. These deficiencies often delay policy-making decisions as no facts or persuasive data is available to guide the policymakers. These details also show that the lack of information and research is the main reason for the cities in the case study facing groundwater problems. Therefore, the urgent attention of decision-makers is required. This may be achieved through a common database, through the establishment of a fund for research (such as that implemented in Bangkok through a groundwater preservation levy) and through international forums to share research findings.

3-2. An agency should be established and reinforced to direct the coordination and facilitation of groundwater policy-making and implementation.

In most of the cities in the case study, there is more than one institute that has different and sometimes overlapping responsibilities in groundwater management. This discrepancy in institutional arrangement becomes an obstacle to the implementation of holistic management planning and implementation.

One such example is in Sri Lanka, where three agencies are involved in groundwater development and research, and there is very poor coordination between them. They very seldom share information, instead blaming each other for failures. Also, in Bandung, the policy of political decentralization assigned the responsibility for policy-making and implementation to the municipality level. This devolution of authority is basically beneficial for water management because it becomes possible to implement water management close to the users. However, in the case of Bandung, the new responsible resulted in an increase in groundwater abstraction. In Ho Chi Minh City, the necessary data is scattered among relevant organizations and is not well utilized in policy-making. On the contrary, in the case of Bangkok, the Department of Groundwater Resources of the Ministry of Natural Resource and Environment is responsible for overseeing activities related to groundwater resources and contributed to the groundwater management.

3-3. Dialogues among relevant stakeholders should be incorporated in the policy-making and review process as a tool for promoting efforts in groundwater conservation.

The stakeholder meetings that were organized in the case studies showed that such gatherings were helpful in enhancing awareness of groundwater issues and mutual understanding among the stakeholders. Lack of proper understanding and awareness of groundwater issues is one of the major barriers to the implementation of groundwater control measures. Therefore, an opportunity such as stakeholder meetings should be incorporated in a management cycle of groundwater to remove the barriers.

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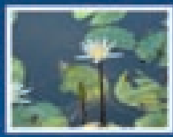
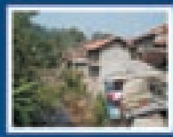


PART II

THE STATE OF GROUNDWATER RESOURCES AND MANAGEMENT IN CASE STUDY CITIES
- Summary of Situation Analysis -

This part presents a summary of the situational 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 is also cited as a reference case.

The status of groundwater resources and the policy measures implemented differs 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 analysis provides a basis for the recommendations presented in Part I.

The data referred to in our analysis was provided by each case study report. 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 facilitated.

1. General Background to the Case Study Cities

1-1. Socio-Economic Conditions

Table 1 summarises background socio-economic information of the case study cities. The population has been steadily increasing in each of the cities. In particular, the population of Bangkok and Colombo doubled in 30 years, illustrating the trend of increasing urban sprawl in the region. It should be noted that the population given in table II-1 is the registered population and that in some cities, such as in Ho Chi Minh City (hereafter HCMC), the number of unregistered population in the city is substantial. Population densities within the study areas vary from 3,944 persons/km^2 in Kandy to 926 persons/km^2 in Tianjin. The values presented here show only the average population of the study areas in their entirety, although the distribution of the settlements is highly uneven. The values, therefore, do not clearly represent the degree of population concentrations in these locations. For example, in Bangkok, Bandung and Tianjin, most of the population is concentrated in the so-called city centres with very high densities.

The per-capita regional GDP (RGDP) during the year 2002-2003 based on reports from each country is also presented in table II-1. The figures in brackets is the per-capita GDP for each country to show the degree to which each city contributes to the economy of the country.

Table II-1. Socio-Economic Status in the Case Study Cities

Country	City	Study Area (km²)	Population (millions)			Population Density (per km²)	Per-capita RGDP[a] (US$)
			1970	1990	2002		
China	Tianjin	11,919	7.1[b]	8.58	10.11	926[c]	3,212 (1,100)
Indonesia	Bandung	2,341	-	4.25	5.72	2,499	1,172 (940)
Sri Lanka	Colombo	1,575	2.67	3.09	4.3	2,730	1,552 (957)
	Kandy	322	1.19	1.05	1.27	3,944	---- (957)
Thailand	Bangkok	2,844	5.2	8.95	10.5	3,727	5,879 (2,190)
Vietnam	HCMC	2,095	---	---	5.3	848	1,060 (480)

a. the numbers in parenthesis are the country per-capita GDP
b. 1978 population
c. The figure is cariculated based on the registered population (The figure of population is permanent population)

1-2. Climatic Conditions

The climate of all case study cities except for Tianjin is influenced by monson climate. As these cities have clear rainy and dry seasons, surface water availability is also highly seasonal. The annual precipitation of each city is shown in figure II-1. The figure shows that Tianjin has a very low precipitation, which is a major cause of the city's "water-stressed" situation. Also, the average maximum and minimum temperature are given in table II-2. The temperatures are good examples for understanding the hot and humid temperate climatic conditions prevailing in the cities.

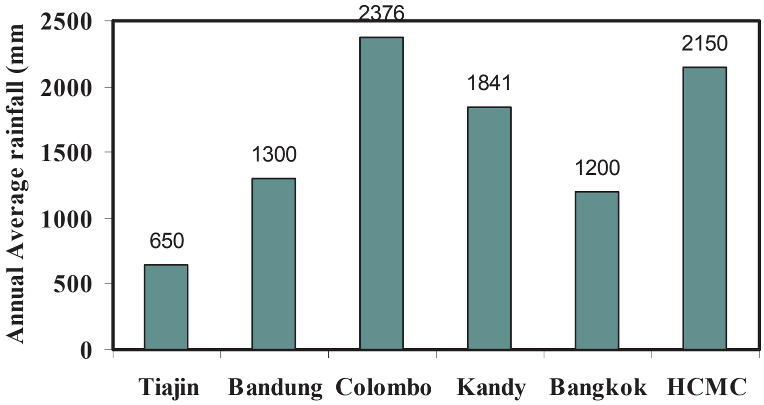

Figure II-1. Annual Average Precipitation

Table II-2. Average Maximum and Minimum Temparature

	Tianjin	Bandung *	Colombo	Kandy	Bangkok	HCMC
Average daily max	17.8	27.2	30.6	29.0	32.7	32.3
Average daily min	8.2	18.1	24.1	20.2	24.1	23.7
Ranges	-7.7–30.7	17.0–29.0	22.3–31.8	18.4–31.4	20.8–34.9	21.1–34.6

Source: World Meteorological Organization (http://www.wmo.ch/index-en.html)
** http://indahnesia.com/indonesia/CLI009/bandung.php*

1-3. Hydrogeology

In most literature, the term "groundwater" refers to water available beneath the ground surface that exists in the spaces between earth materials, or even in rock openings such as fractures in crystalline metamorphic rocks. In a more technical sense, "groundwater" refers to the underground water that can flow freely into a well, tunnel, and spring. The productivity represents the ability of the aquifer to replenish itself or, in other words, its ability to store and transmit water. Aquifers may be formed through a variety of geological situations and may be found in a variety of different settings. Water in aquifers accumulates in and fills the pores above this impermeable barrier. The zone where the pores are filled with water is called the zone of saturation. An aquifer may be confined if its upper surface is not the water table but an impermeable layer of rock, such as shale. If the upper surface of an aquifer is the water table itself, then the aquifer is said to be unconfined.

In general shallow aquifers are unconfined, but at greater depths, they are often partially confined by a stratum of very low permeability known as an aquitard or they are fully confined by an overlying impermeable stratum known as an aquiclude. Depending on the location, water in confined aquifers can be under elevated pressures. Therefore, when wells are drilled, the water rises above the top of the confined aquifer and even as far as the ground surface, creating an artesian well.

From the above, it is can be easily seen that the hydrogeological characteristics greatly influence the productivity of an aquifer. The properties of the aquifer are determined by, most importantly, conditions such as the porosity of the strata of which the aquifer is composed. Of secondary importance is the condition where water is stored in and flows through fractures. The different ways that water is stored and flows through the rock control both the volume of storage and its relative mobility. In this regard, the aquifer setting can be classified into broad types that encompass the types of rock, the environment in which they were formed and the effect of subsequent geological processes. These sorts of groupings not only help in understanding the resources of a region but also provide a means of using past experience of similar settings to improve utilization of the resource.

The physiographical and hydrogeological environment in each study area can be summarized as given in table II-3 below.

Table II-3. Physiographical and Hydrogeological Features in the Region

City	Physiographic features	Hydrogeological setting
Tianjin	Mainly plain morphology with a mountainous region in the north	Mainly semi-consolidated alluvial sediments intercalated by sandy water-bearing layers and soft clay layers divided by a fracture zone, separating fresh and saltwater between the clay and sandy layers. Moderate crevice aquifers in the north mountainous areas
Bandung	Hilly morphology unit with a central plain area encircling volcanic cones	Unconsolidated interbedded lapillus silt and water-bearing sand layered intermontane volcanic system with moderate to low primary porosity separated by faults.
Colombo	Coastal plain morphology with a moderately undulating terrain	Mainly metamorphic rock with a thin weathered mantle and, in some areas, a weathered laterite basement complex. Groundwater exists both within the laterites and as semi-confined crevice water.
Kandy	Hilly terrain plateau with undulating plains and hillocks formed by drainage paths separating them	Metamorphic rock formation with a thin weathered low permeable mantle underlain by fresher rock, made up of moderately fractured zones having few groundwater resources.
Bangkok	Plain morphology only a few meters above sea level. Sits on a soft to stiff dark gray to black clay layer commonly known as Bangkok clay.	Unconsolidated and semi-consolidated sediment intercalated by clay layers and containing large volumes of voids for water storage, which form several confined aquifers that are distinguished into eight layers
HCMC	Diverse topography with plain morphology	Unconsolidated and semi-consolidated sediments intercalated by raw sandy water-bearing layers and very thin soft clay layers separating into several semi-confined aquifers

With respect to the hydrogeological setting and aquifer formation of each city, the case study locations can be further separated into three distinct groups of cities having;

1. Stratified layer aquifers with interbedded clay and sandy water-bearing layered formations (Bangkok, HCMC and Tianjin),
2. Stratified layer intermontane aquifers with interbedded lapillus silt and sandy water-bearing layered formations (Bandung), and
3. Hard rock-based metamorphic rock aquifer formations (Colombo, Kandy and northern Tianjin).

According to these groupings, the hydrogeological features and the condition of the aquifer in HCMC, Tianjin and Bangkok are characterized by semi-consolidated to unconsolidated interbedded alluvial formations of a similar nature, while the conditions in Bandung, Colombo and Kandy are different. Being mindful that the hydrogeological features in two places will never be identical, however, this sort of assessment can help each city to better understand the future of its own groundwater resources by learning from the advantages and disadvantages of cities with similar settings. Therefore, we feel that the problems experienced from groundwater over-exploitation in cities with similar hydrogeological features, such as Bangkok and Tianjin, could help cities such as HCMC that has only a very short history for groundwater exploitation to formulate strategies to minimize and avoid the possible anticipated problems.

2. The State of the Groundwater

In the year 2000, twenty-three cities in the world had a population of more than 10 million. Over half of them rely upon, or make significant use of, local groundwater (Morris et al. 2003). Most of these cities that are located in developing regions are particularly found in Asia and Central and South America. In addition to the large population, heavy concentration of industrial activities has placed very severe stress on water resources in urban areas.

Box II-1. Overview of Water Consumption and Future Trends of Two Major Factors

Contributing to Changes in the Groundwater Use - Population and Economic Trends

Increasing Water Consumption in Asia: The Asian region has experienced significant increase in water consumption over the last century (figure II-2). There are a number of factors contributing to the change in water demand, such as population, economic activities and climate change. Of these factors, population growth is regarded as contributing to the change in water demand in the coming few years (Oki 2004). About 80 percent of the water resources in the region is consumed by the agricultural sector, but consumption in the industrial and domestic sectors has been rapidly increasing following economic development and the resultant change in lifestyles.

Continuous economic development and its vulnerability: Asia's economy saw rapid growth over the last decade. The average rate of growth in real GDP between 1996 and 2006 in Asian countries, excluding Western Asia, was 5.8 percent, which is higher than the rest of the world (United Nations 2006). Asian economies once slowed due to the Asian financial crisis in 1997-1998, but it quickly recovered and achieved 7.3 percent growth in 2004, the best growth performance since the crisis (ADB 2005). The growth is expected to continue in the next few years, but the Asia's economy depends on external demand and therefore could be influenced by an external downward risk.

Growing urban population: The population in Asia increased by 2.5 billion between 1950 and 2000, and the region is now home to about 3.6 billion people representing nearly 60 percent of the world's total population. The rate of population growth has recently slowed, but the population is forecast to increase to 5.2 billion by 2050.

The increase in the population has been most strongly marked in urban areas. About half the increase in population in the fifty years to 2000 was observed in urban areas. The present urban population is about 1.3 billion, and it will double by 2030. According to forecasts prepared by the United Nations, more than a half the population of Asia will live in urban areas in 2025. Figure II-3 shows the rate of increase in urban populations in the countries where the case study cities are located. All the countries are expected to experience a steady increase in urban population.

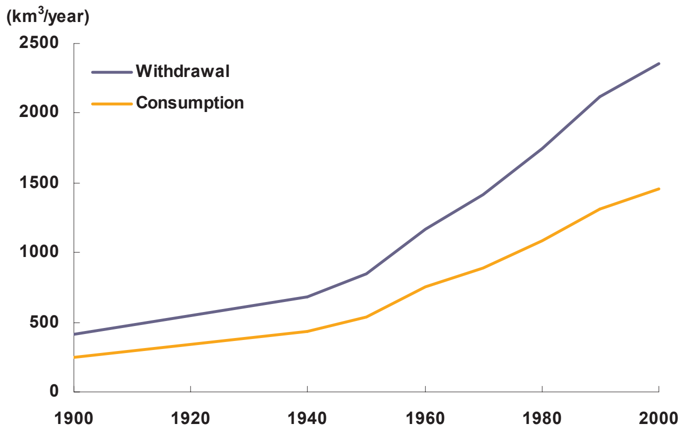

Figure II-2. Water Extraction and Consumption in Asia between 1950 and 2000

Note: The figure in 2000 is projection.

Source: http://webworld.unesco.org/water/ihp/db/shiklomanov/summary/html/sum_tab7.html

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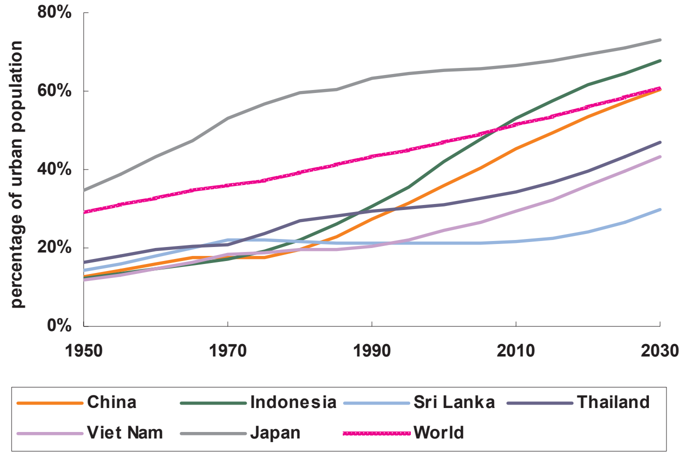

Figure II-3. Percentage of Urban Population in Selected Countries in Asia

Note: The urban population is the de facto population living in areas classified as urban according to the criteria used by each area or country. Data refers to 1 July of the year indicated and is indicated in thousands.

Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision, http://esa.un.org/unpp, [16 February 2006].

2-1. Availability of Water Resources and Abstraction

Table II-4 shows the availability of renewable surface water and groundwater and the volume of abstraction. Tianjin showed a high level of stress both in surface water and groundwater. Further, groundwater abstraction in HCMC exceeds the so-called safe yield (renewable amount) for the area. The renewable surface water resources are almost fully utilized in Tianjin and Bangkok, which means that the scope for using surface water as the alternative to groundwater is limited. Although not indicated by the figures, in other cities, too, the surface water is stressed. In HCMC and Bandung, the surface water bodies are highly polluted, and in Colombo, the availability is highly variable throughout the year. All these facts can motivate people to use groundwater more than surface water. The facts also reveal that the availability of surface water as an alternative source is highly questionable.

Table II-4. Status of Water Resources within the Case Study Cities (million m^3/year)

Resource \ City	Bandung	Tianjin	HCMC	Bangkok	Colombo	Kandy
Groundwater						
Renewable	1,159	827	183	2,844	588	176
Abstracted	170	748	342	800	160	29
Stress (%)*	14.7	90.4	186.9	28.1	27.2	16.5
Surface water						
Renewable	-	2,290	734	30,000	9,269	2,384
Abstracted	-	1,679	405	30,000	1,879	1,900
Stress (%)*	-	73.3	55.2	100	20.3	79.7

**Water stress is the ratio of abstracted volume to the renewable ground/surface water.*
Note: Bangkok values are for the whole Chao Phraya basin.

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2-2. Dependency of Groundwater Resources and Beneficial Use

Figure II-4 illustrates that the recent dependency on groundwater is in excess of 40% in all cases other than Bangkok. The high dependency on groundwater and less availability of surface water as an alternative water source may constitute a constraint for groundwater resource management.

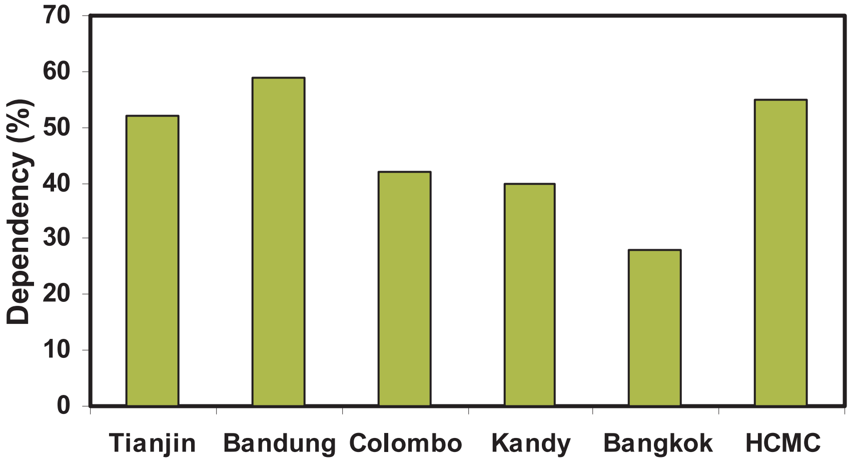


Figure II-4. Recent Dependency on Groundwater

In today's context, cities require water for various purposes, such as for public or private domestic water supply or industrial and commercial use. In most cases, the groundwater has been the most attractive source to meet water requirements. Table II-5 shows the beneficial use of groundwater in each case study city. In Bandung, HCMC and Bangkok, most of the abstracted groundwater is used for industry, and future groundwater demand in these cities is contingent on the relationship with the water usage of industry. On the other hand, agricultural use is dominant in Tianjin, while other cities make minimal use of groundwater in irrigation.

Table II-5. Beneficial Use of Groundwater in Case Study Cities

City / Beneficial use	Bandung	Tianjin	HCMC	Bangkok	Colombo	Kandy
Industry use (%)	80	15	57	64.5	>10	>5
Domestic use (%)	20	23	43	34	<90	<95
Agricultural and other use (%)	-	62	-	1.5	>0.5	>0.5

An analysis of the per-capita water abstractions in the case study cities given in table II-6 indicates that there is a wide variation in values within the study locations. The total water consumption per person is very low in Bandung and Kandy (87 and 102 l/d, respectively) and very high in Bangkok and Tianjin (520 and 432 l/d, respectively). The high per capita water consumption water and groundwater abstraction in Bangkok reflects the direct influence from the high level of industrial activity in the city, and in Tianjin, the high percentage of groundwater use in agriculture. In addition, the very low water consumption in Bandung despite its high level of industrial activity clearly shows the limitation of the existing data. However, this is good example of the circumstances in a typical urban area in the Asian region where, conjunctive groundwater usage among the industrial, domestic and agricultural sectors exist.

Table II-6. Per Capita Water Use

Study area	Groundwater use		Surface water use		Per-capita[+] total use
	Total*	Per-capita[+]	Total*	Per-capita[+]	
Bangkok	1.65	128	4.15	392	520
Bandung	0.30	51	0.21	36	87
Colombo	0.44	102	0.61	142	244
HCMC	0.94	125	0.77	103	228
Kandy	0.05	39	0.08	63	102
Tianjin	2.32	229	2.05	203	432

** Million m^3/day, + litres/day. capita*

2-3. Trend of Groundwater Use

Facts about the groundwater use in the six case study areas over the past two decades are tabulated in table II-7 below. Here, total groundwater use represents total groundwater abstraction within a study region from both the registered wells that are usually metered and unregistered wells, where the volume of abstraction is estimated. Both the total as well as registered groundwater abstraction is continuing to increase in all cities except Bangkok. The increase in the use of water through other alternate sources in all cities is very marginal except in Bangkok.

Table II-7. Trend of Daily Water Groundwater Use

Study area	Registered GW use			Total GW use			Alternate water			GW contribution (%)		
Year	1980	1990	2003	1980	1990	2003	1980	1990	2003	1980	1990	2003
Bangkok	0.54	0.50	1.7	1.36	1.50	2.2	1.20	2.95	4.15	53	34	35
Bandung	0.08	0.13	0.14	0.17	0.28	0.30	0.10	0.18	0.21	63	61	59
Colombo	-	-	-	-	-	0.44	-	-	0.61			42
HCMC	0.15	0.25	0.53	-	-	0.94	-	-	0.77	-	-	55
Kandy	-	-	-	-	-	0.05	-	-	0.08	-	-	38
Tianjin	-	1.91	2.32	-	-	-	-	2.21	2.1	-	46	52

Note: Alternate water includes river water, transferred water, reused water and spring water

2-4. Problems Associated with the Over Exploitation of Groundwater

There are a number of well-known undesirable consequences of groundwater development. In some areas for part of the time, most aquifers tend to exhibit a decline in the water level as part of their natural cycle even when they are not exploited. This may be seasonal, during a normal dry season, or it may be longer term in response to a prolonged drought. However, in extreme situations such as in the case of over exploitation, an aquifer can easily become effectively dewatered, with groundwater levels having become so severely depressed that the aquifer approaches exhaustion resulting in rapid declines in yield and even ultimately wholesole abandonment. For water levels to recover under these circumstances, the resultant forced reduction in abstraction needs to be very stringent, exceeding the long-term rate of recharge. The process may take many years or even decades to occur and, in the worse, the aquifer may not recover at all. This problem is certain to create severe socio-economic consequences. In most cases the consequences are slow to develop, and are not apparent until the problem is well-entrenched. In addition, if alluvial deposit formations are initially formed as soft sand, silt or mud, groundwater pumping and subsequent drawdown can result in the effect of reducing the pore water pressure and thus increasing the effective stress from the overlying strata on the matrix of the aquifer. When the increase in effective stress is greater than a critical value, the land will subside.

Box II-2. General Path of Groundwater Development

When groundwater development in case study cities is reviewed, it appears to follow a similar path that reflects the development of the city. Figure II-5 shows groundwater development in the city of Osaka, Japan as an example case.

In Osaka, groundwater was initially used for production and miscellaneous purposes within its natural recharging capacity *(first phase: modest development)*. The resource then started to be exploited intensively in the course of industrialization starting in the 1920s. There is no available data on groundwater extraction at that time, but the rapid speed of subsidence of the land suggests intensive use of groundwater. In this period, groundwater problems began to be recognized *(second phase: intensification of groundwater use beyond theist recharging capacity and emergence of groundwater problems)*. To attenuate groundwater problems such as land subsidence and water table drawdown, groundwater control measures were introduced and abstraction volume began to decrease *(third phase: reduction of abstraction with control measures)*. After the control measures succeeded in controlling excessive abstraction and groundwater problems abated, groundwater began to be used in a stable way under the controls *(fourth phase: stable abstraction with proper controls)*.

Through the control measures, groundwater is used within its recharging capacity and as a consequence the groundwater level has stabilized. However, the strict restrictions on groundwater abstraction over half a century is now creating the problem of an excessive increase in groundwater which may damage the foundations of building infrastructure and increase of the risk of liquidification. To avoid this unexpected result of groundwater exploitation control, the strict control of abstraction should be reviewed with optimal use of groundwater resources.

Asian cities, including the case study cities referred to in this report, are undergoing development and groundwater has been increasingly exploited in line with socioeconomic development. Cities that are now at the beginning of the development path should take action not to follow the same path of unsustainable groundwater development of the precedents.

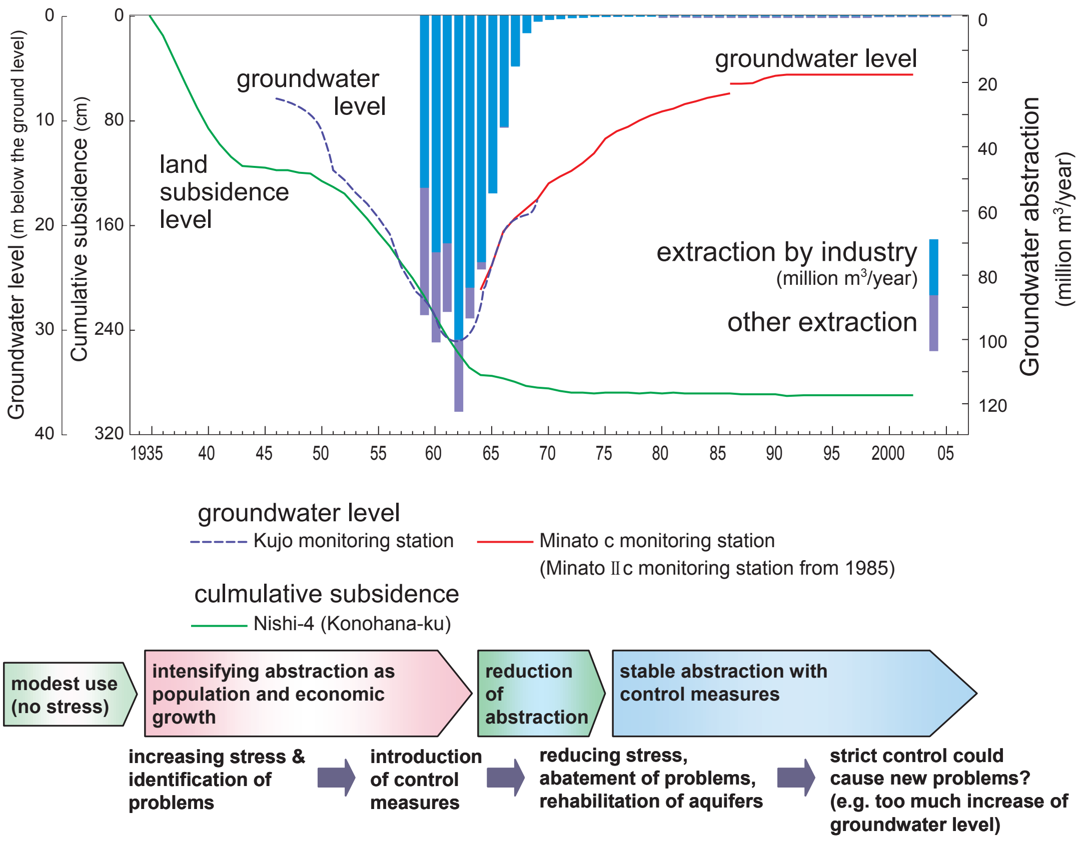


Figure II-5. General Path of Groundwater Development (Osaka City as an example)

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

Throughout the case study regions too, over-exploitation of groundwater has produced widespread problems caused by the rapid reduction of the resource and land subsidence. The intensity and the cumulative extents of water level depletion and land subsidence in the years 1980, 1990 and 2003 are tabulated in table II-8. The accumulated drop in the water level and the subsidence are given in figure II-6 According to the data, the drop in the groundwater level continues in all cities other than Bangkok and land subsidence is observed in Bangkok, Bandung and Tianjin. In comparison to the extensive land subsidence experienced in Bangkok and Tianjin, the land subsidence data for Bandung is very modest. The localized land subsidence that occurs in the vicinity of heavily abstracted bore holes found in HCMC is a good example of the lack of proper monitoring that is common in the region.

Table II-8. Effects of Groundwater Overuse (maximum values observed)

Study area	Average drop in water level (m/y)			Average land subsidence (mm/y)		
	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 values in this table not average but apply to specific locations.
(-) Data is not available

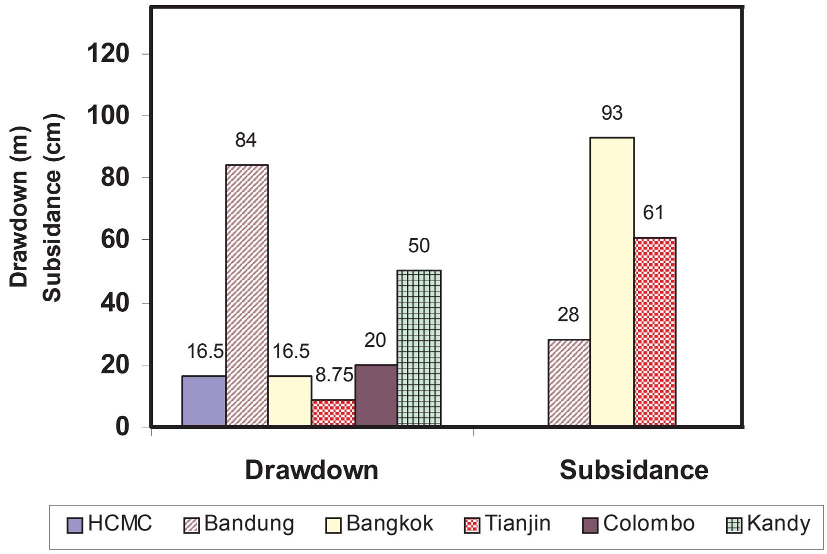


Figure II-6. Accumulative Drop in the Water Level and Land Subsidence in the Study Area

Note: The accumulated values given here for drawdown are since 1992 in the case of HCMC, since 1920 for Bandung, since 1976 for Bangkok, since 2001 for Tianjin, since 1985 for Colombo and since 1981 for Kandy. In the case of Bandung, the values are since 2000, and in the case of Bangkok, measurements were made with reference to a 1930 benchmark, although land subsidence was recognized as a social problem in 1969. In Tianjin, the values are since 1981, although the history is since the 1960s.

The degree of land subsidence per unit drop in the water table is 60 mm/m in Bangkok. In Tianjin it is 50 mm/m and in Bandung it is 3 mm/m. The above calculations show that the degree of subsidence to unit drop in the water table is much less in Bandung in comparison to that of Bangkok and Tianjin where observed past land subsidence had been severe. Although the accuracy of the available data is limited, this may suggest that in regions such as Bandung, the problem of land subsidence is minor and therefore the present focus needs to be on controlling the problem of the drop in the water table rather than land subsidence. (Hydro-geologically, too, the aquifer setting in Bandung is believed to be less susceptible to subsidence, unlike Bangkok and Tianjin, as shown in table II-3.) It should be noted here that the calculated water stress potential presented in table II-4 has a very poor relationship with groundwater-related problems experienced in the cities concerned. For example, in HCMC where the groundwater stress is very high (186.9%), the problems are very modest compared to those in Bandung where groundwater-related problems are so severe but with very small stress (14.7%). This may be mainly because of the very poor understanding of resources within the region or may be due to the high concentration of abstraction. The lack of data to provide a clearer analysis is again highlighted as the main cause. With very little emphasis given to research and monitoring, improvement in this respect is very bleak at present.

2-5. Deterioration of Groundwater Quality

Groundwater contamination has been observed in many Asian cities, and in some cases, it can represent a risk to health. Typical groundwater pollutants detected in Asia include arsenic, fluorine, heavy metals, coliform, salinity, pesticides, petrochemicals, nitrate, ammonia and Volatile Organic Compounds (VOCs), such as trichloroethylene. The causes of contamination can be broadly categorized into two, namely: (1) naturally occurring pollutants, and (2) anthropogenic pollutants. In addition to these two categories, aquifer contamination caused by the tsunami observed in the Asia-Pacific following the earthquake under the Indian Ocean on December 26, 2004 is also worth noting as the different type of contamination.

The following part is a brief introduction to groundwater contamination with the prominent pollutants observed in the case study cities. Arsenic is a naturally occurring pollutant that has been identified as a serious problem. In Bangladesh, for example, it is estimated that more than 35 million people drink water contaminated with arsenic. In the case study cities, strong cases of arsenic contamination of the groundwater are not currently reported. Instead, the fluorine issue was selected for discussion in this report as an example of naturally occurring pollutant. Of the anthropogenic pollutants, salinity, nitrate and coliform are discussed as the most commonly reported pollutants in the case study cities, together with the VOCs that may surface with the industrialization of the cities. In addition to these pollutants, contamination caused by the tsunami is briefly introduced.

Table II-9 summarizes the typical groundwater pollutants detected in the case study cities, based on the case studies conducted. The table includes the cities observing high values of pollutants that exceed the quality standards, along with those that are recently observing relatively high monitored values, thus requiring continuous attentions.

Table II- 9. Typical Pollutants Observed in the Case Study Cities

	Tianjin	Bandung	Colombo	Kandy	Bangkok	HCMC	Osaka
Fluorine	×				×		
Metals (e.g. manganese, iron)		×	×		×	×	
Heavy metals (e.g. cadmium)		×				×	×
Nitrate		×	×		×	×	
VOCs (e.g hloroethylene)							×
Coliform	×	×	×	×		×	
Salinity	×		×		×	×	

Note: This matrix is created based on the information provided by the respective case studies. The table may not include all the pollutants in each city.

(1) Naturally occurring pollutants

• **Fluorine**

Fluorine is a typical naturally occurring pollutant in groundwater that is observed in many parts of the world For example, aquifers in the drier regions of north-western India, northern China, and parts of Thailand and Sri Lanka are rich in fluoride deposits (Brown et al. 2001). It exists naturally in the form of a number of fluoride minerals, such as fluorspar. The excessive intake of fluoride has a negative effect on health, resulting in skeletal and dental fluorosis, although a small concentration of fluorides is of benefit to the teeth.

In Tianjin, it has been observed that fluorine in aquifers exceeded the standard level, especially in coastal areas. It is reported that more than 75 % of monitored groundwater values exceeded the standard level in the coastal zone of the city as of 2002. The survey showed the highest concentration of 6.6 mg/l in the Tanggu district of Tianjin. The drinking water standard for fluorine was met in only limited areas such as the mountainous regions in the northern part of Jixian County. At present, such measures as aluminum precipitation are applied to reduce the fluorine level in the water from the wells. Many cases of health problems related to fluorine contamination have also been reported in Tianjin, thus requiring special attentions to the contamination. Given the pervasive fluorine contamination in aquifers, the municipality of Tianjin currently has a plan to further develop the infrastructure for piped water supply systems, especially in the rural agricultural areas. In some districts of the Bangkok area, as well, fluorine was detected in the monitored wells exceeding the standard level, thereby making it necessary to be continuously vigilant of the pollutant.

(2) Anthropogenic pollutants

• **Salinity (Chloride)**

The salinization of aquifers (chloride contamination) may occur for several reasons. One of the commonly observed causes is saltwater intrusion due to the lowering of the water table resulting from excessive groundwater abstraction, and this phenomenon is seen in the case study cities as well. Another type of salinization is due to the use of wastewater in irrigation.

The salinization of aquifers has been detected in many Asian cities, including Bangkok, HCMC, Tianjin and Colombo. Figure II-7 shows the chloride concentration of the Phra Pradaeng aquifer—one of the eight aquifers under the Bangkok case study area. The results indicate a high value of chloride at some monitoring locations that far exceeds the allowable limit of 250 mg/L. In HCMC, saltwater intrusion has been observed in some of the districts and this phenomenon seems to have been escalating recently, with a continuing drowdown of the water table due to excessive groundwater abstraction in order to meet the growing water demands in the city. The maximum monitored value of chloride in HCMC was as high as 79,833 mg/l in 2001, showing that the location being monitored had a high level of salinity. These cities are located near the coastline, and are naturally prone to saltwater intrusion. Aquifers contaminated by salinity may result in the wells being abandoned in most cases, simply because saline groundwater is not suitable for drinking, and desalination technologies tend to be quite expensive or infeasible in many developing countries.

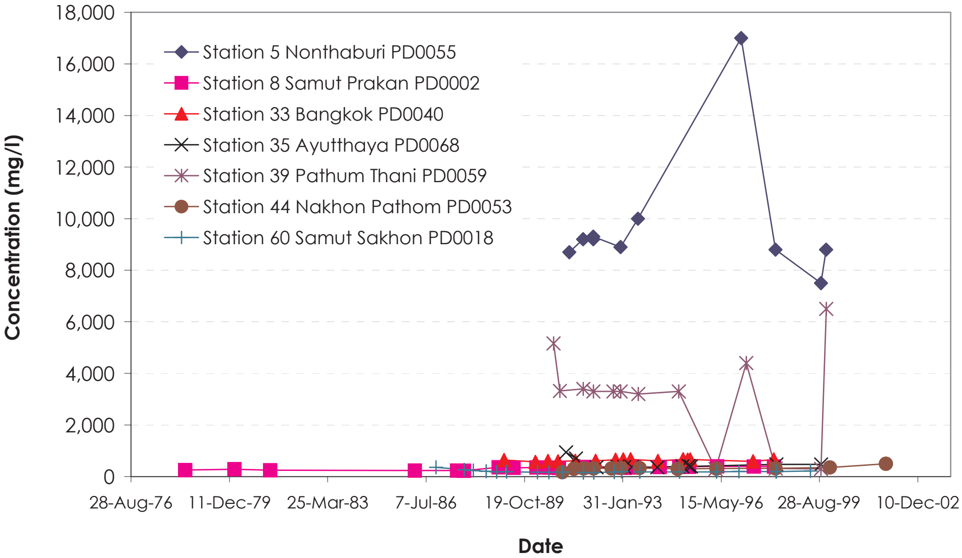


Figure II-7. Chloride Concentration in Phra Pradaeng Aquifer, Bangkok

Source: Department of Mineral Resources, Royal Thai Government

PART II

- **Nitrates**

The nitrate contamination of aquifers is also a serious problem that pervades Asia as well as other parts of the world, including the United State and Europe. Nitrate contamination can be caused by diffuse sources as well as point sources. Nitrogen fertilizer use in agriculture, a diffuse source, is considered one of the main causes of the nitrate contamination. Point sources of contamination include, but not limited to, effluent from on-site sanitation facilities such as septic tanks, and industry. Various factors influence the concentration of nitrates in groundwater, including precipitation, soil type, and geological features.

Nitrate was the most frequent type of pollutant detected in groundwater samples in a 1982 nationwide survey conducted in Japan. In the survey, it was found that 10 % of all well water samples exceeded the allowable limit for nitrate in drinking water (Okada and Peterson 2000). Among the other case study cities, the monitoring in Bandung, HCMC, and Kandy detected rather high values of nitrates in aquifers. In Bangkok, as well, several monitored wells exceeded the allowable limit of 45 mg/l for drinking purposes in Thailand, although most of the wells that were monitored complied with the value. The case study reports indicated that the highest values of nitrate monitored in Bandung (1991) and HCMC (2001) were 293.7 mg/l and 95.9 mg/l respectively although the highest value in Bandung tended to decrease in later years, according to the monitoring survey in Bandung. Apart from the point sources, the impact of the excessive use of fertilizer in suburban farms is a possible cause of the high levels of nitrate contamination. To effectively control nitrate contamination, it is necessary to continuously investigate the impact of fertilizers.

- **Coliform**

Coliform contamination, which could threaten human health causing such problems as diarrhea, may be the result of effluent from on-site sanitary facilities, cesspits, latrines and effluent of livestock manure. Coliform contamination mainly in shallow aquifers is observed in HCMC, Bandung, Tianjin, Colombo and Kandy. In HCMC, coliform has been detected in shallow aquifers as well as relatively deep aquifers. This may have occurred due to the transfer of the coliform through the interconnection between the shallow and deep aquifers. Surveys conducted in Bandung revealed that most of the tested samples did not meet the standard value, indicating that coliform contamination now appears to be quite pervasive in the Bandung Basin. In this way, coliform contamination indeed exists as a common problem in Asian cities, especially where sanitary conditions are poor. Table II-10 shows the highest monitored value of total coliform (MPN/100 ml) in HCMC, Bandung, and Kandy based on the case study reports. It is shown in the table that the contamination level at some monitoring locations can be quite high, especially in Bandung and HCMC, although both cities also had wells where no colifom was detected.

In the two districts of HCMC, more than 70% of septic tanks installed are reported to be improperly constructed, with septic tanks not being lined with concrete. In Bandung, only 20% of septic tanks installed in houses, apart from the approximate 15% of people serviced with a central sewer system, are considered to be properly constructed or managed and much of the wastewater is presumed to be discharged directly into the rivers. In the case of Colombo, a central sewer system is available only within the city area. In all other areas, people mostly use septic tanks or soakage pit systems. Nevertheless, the water table in many areas around Colombo is quite shallow, and it can be suspected that a high degree of groundwater contamination may occur due to the effluent from on-site sanitary systems. It is also worth noting that dug wells in these cities are not properly constructed in some cases, and do not meet the technical standards, such as the minimum required distance to the closest on-site sanitation, which is ten meters in the case of Bandung. These conditions would increase the probability of contamination. In addition to the poor conditions of on-site sanitary systems and dug wells, surface water pollution, which is also frequently observed in many Asian cities, should not be neglected as a source of groundwater contamination. A study shows that the coliform level in the Saigon river estuary in HCMC was very high, ranging between 0.07 million and 0.12 million (MPN/100 ml) in 2000.

Table II-10. Monitored Values of Total Coliform in Three Cities (MPN/100 ml)

City	Bandung	Kandy	HCMC
Year	2005	2005	2001
Highest value	0.11*	144	0.93*

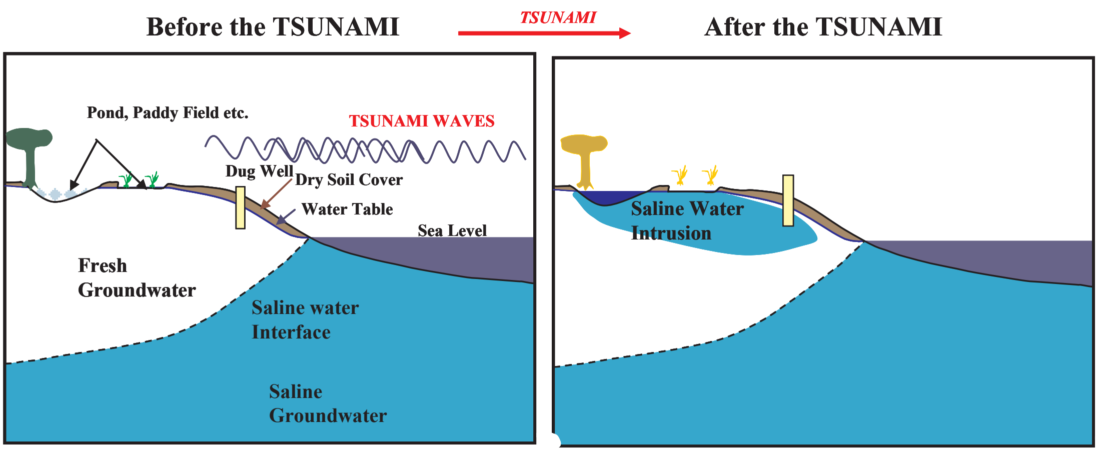
**Million MPN/100 ml*

• **Volitile Organic Compounds (VOCs)**
Volatile Organic Compounds (VOCs), which include such chemical substances as trichloroethylene and tetrachloroethylene, have also been serious problems. These substances have been detected in aquifers and soils particularly in industrialized countries such as the United States. Japan has also experienced contamination due to VOCs over the past decades. In fact, a nationwide survey conducted in 1982 showed that trichloroethylene and tetrachloroethylene were detected in about one of three well water samples (Okada and Peterson 2000).

In the case of trichloroethylene, the pollution source can be cleansing solvents used in industries such as semi-conductor factories. Studies have revealed that leakage from solvent tanks and disposal of wastes that contain high concentration of the solvents are the main sources of contamination. Although there is currently no clear indication from the case study cities about obvious contamination with VOCs, there is the possibility of the contamination caused by VOCs in the future, with the likely development of relevant factories in the industrializing cities in Asia. In HCMC, for example, the gross output of the metals industry increased drastically over the last decade from 187,713 million Vietnamese dong (11.8 million USD) in 1992 to 3,128,417 million dong (196.7 million USD) in 2002 on a constant-price base, according to the case study report. It can be inferred that the potential threat of VOCs contamination in aquifers cannot be denied as the related industries grow rapidly, unless the substances are handled properly. Given the Japanese experience, it is strongly recommended that precautions and preventive measures be taken to avoid contamination with VOCs

(3) Contamination caused by the tsunami

An earthquake occurred under the Indian Ocean on December 26, 2004, with its epicenter located off the west coast of northern Indonesia. The resulting tsunami had a devastating impact on Asian countries. The tsunami caused serious groundwater contamination, especially in the shallow aquifers, due to saltwater intrusion and effluent from sanitary systems that were devastated in many parts of the affected countries such as Sri Lanka. For instance, the results of groundwater quality tests conducted in Sri Lanka after the tsunami showed a high level of contamination, such as salinization and coliform, in many wells. It has been revealed that around 62,000 wells in the country are estimated to have been polluted by saltwater intrusion, sewage and other pollutants. Some tsunami-hit areas lacked water supply systems, and therefore had to rely on groundwater for domestic purposes despite the contamination. Consequently, some health-related problems resulted from the use of contaminated groundwater. Figure II-8 represents the intrusion of saline water into the shallow coastal aquifers in Sri Lanka, caused by the tsunami.



Drawing by Dr. Gemunu HERATH and Dr.Shinichiro OHGAKI, (2005)
Freshwater Resources Management Project,
Institute for Global Environmental Strategies, Hayama, Japan

Based on the information from Dr. Atula SENARATNE,
Senior Lecturer in Geology, University of Peradeniya, and also the current Chairman of Water Resources Board, Sri Lanka

Figure II-8. Saline Water Intrusion into Shallow Aquifers Caused by the Tsunami

3. Socio-Economic Changes and Their Impact on Groundwater Resources

3-1. Urbanisation

The process of rapid urbanization observed throughout the Asia region, including the cities concerned, has altered the natural setting of the environment in many ways. One such example is the change in land coverage where the land surface is completely disturbed and changed to either denuded or paved (developed) land. This not only reduces the groundwater recharging area but also reduces the direct infiltration of excess rainfall, and thereby increases the surface runoff that quickly removes the rainwater, influencing the total amount of infiltration. The recently observed key land use changes within the case study areas are summarized in table II-11.

The data from the case study cities substantiate the above concerns and shows the urgent need to re-establish the recharging potential within the basins. Built-up areas in all cities and, most significantly, in Colombo have expanded rapidly, replacing either the forest coverage or agricultural land (i.e. vegetation). In the case of Bandung, and especially in Colombo and Kandy, the change in agricultural land is mainly from paddy land. Further, in Colombo and Kandy, the cropping efficiency in the late seventies was nearly 200% with two cultivation seasons, while in the last decade, this dropped to an average of 140%. This has tremendously impaired the degree to which the paddy fields are waterlogged and thereby reduced the subsurface flow and recharge influencing the groundwater resources in the regions.

Table II-11. Land-Use Changes (within the Past 10 Years)

Land-Use Type	Change (%)				
	Tianjin	Bandung	Colombo	Kandy	HCMC*
Agricultural land	-2.9	-47.3	39.6	-4.3	-7.8
Build-up land	8.6	49.3	933.1	48.2	41.5
Forests	NA	-43.6	-16.2	110.4	-8.6
Water bodies	-0.3	-31.9	-59.4	8.3	NA

**During 2000 to 2003 period*

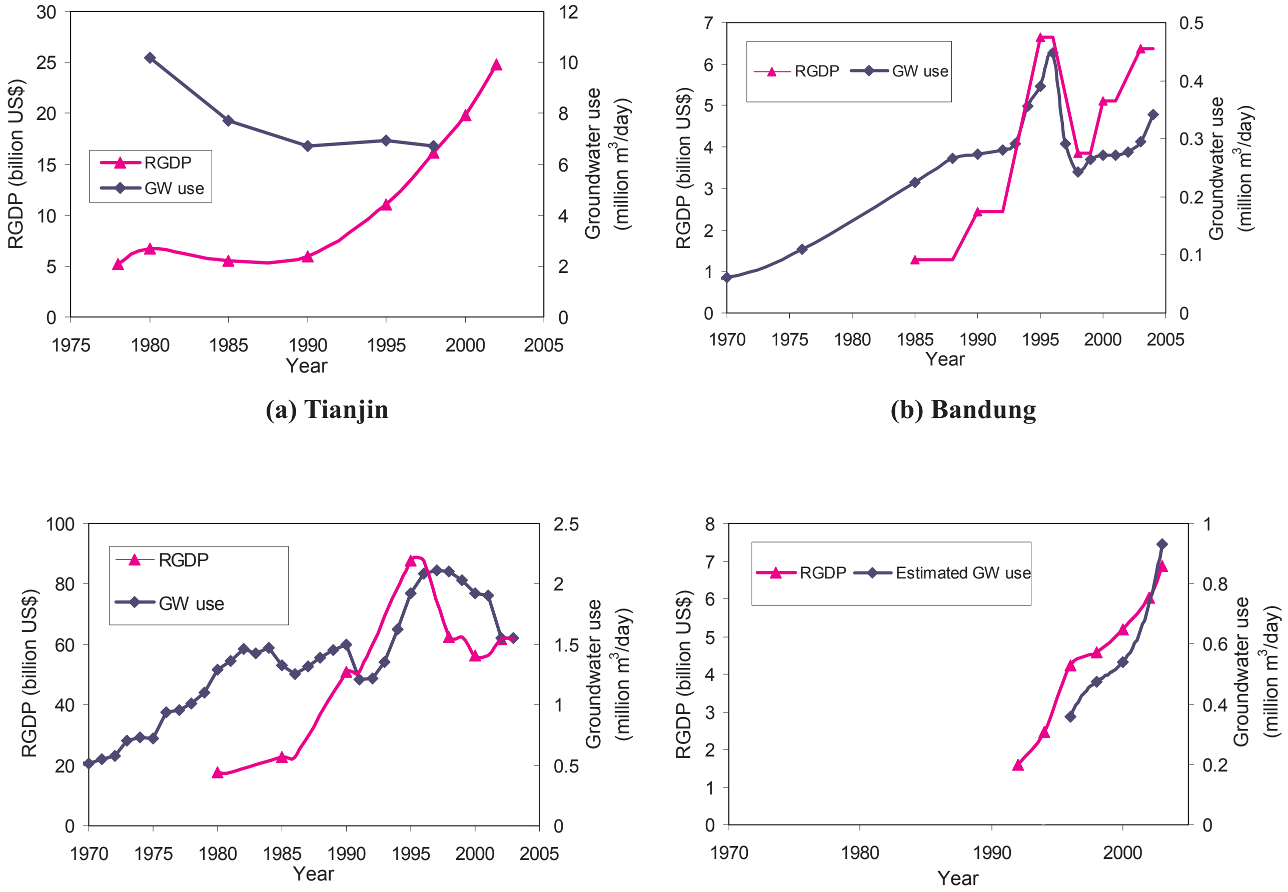
Another key factor influencing the so-called "safe yield" of an aquifer is the degree of recharging capacity available (the "safe yield" of an aquifer in most literature is defined as the amount of water that can be withdrawn from a particular aquifer without producing undesirable consequences). As most of the groundwater resources is mainly renewed (recharged) directly from precipitation through infiltration into the saturated zone, maintaining the recharge potential of an aquifer seems essential for the sustainability of that aquifer. In this regard, a key challenge today is to demarcate and preserve the recharging area within the aquifer basin. Although identifying the exact recharging area for an aquifer is almost impossible, it is believed that vegetation cover and the water bodies within an area are the main potential recharging zones.

3-2. Economic Growth and Groundwater Abstraction

Figure II-9 shows that there is a strong correlation between historical groundwater use and economic growth (in terms of study area RGDP and industry RGDP) in Bandung and HCMC. On the other hand, in the case of Tianjin, the trend is the reverse where groundwater use declined with increased RGDP. Bangkok's groundwater use had increased as the city's grew since the late 1960s, whereas recent data in Bangkok too shows a similar variation as in Tianjin. The differences in the correlation between economic development and groundwater abstraction are closely related to the effectiveness of groundwater abstraction control. In Tianjin, groundwater abstraction control measures were implemented in the 1980s, which is the cause of the decline of groundwater use. In Bangkok, groundwater abstraction control was introduced in 1977.

Because the control was rather ineffective, groundwater use itself increased. However, the correlation between economic development and groundwater use is rather weaker than Bandung and HCMC, where there are no practical measures. The recent decline in groundwater use despite economic recovery is supposed to be the result of the recent strengthening of groundwater control measures in Bangkok after 2000.

Most of the RGDP in the case study cities is from industrial activity, signifying that the two are in directly proportion. Therefore, groundwater use in the industrial sector is the key to future groundwater demand, particularly in cities where the dependency on groundwater resources in the industrial sector is high, namely Bandung, Bangkok and HCMC.



(a) Tianjin

(b) Bandung

(c) Bangkok

(d) HCMC

Figure II-9. Historical Groundwater Use and Economic Development

3-3. Water Supply and Sanitation

(1) Piped water coverage

Another reason for excessive groundwater use in the case study areas is the poor existing water supply coverage. The coverage details in the case study cities are presented in table II-12. The data shows very poor water supply in the cities. The condition is very severe in suburban areas where it is less than 22% in all cities. In Bandung, even in the urban area, coverage is only 40%. Also, the increased coverage in Bangkok during the past two decades is commendable and can be a critical factor in the recent reduction in groundwater use. This data does not clearly demonstrate that controlling groundwater use is a major task for the authorities concerned.

Table II- 12. Piped Water Service in the Case Study Cities (by population coverage)

(unit: %)

Year	Bandung		Bangkok		Colombo		HCMC		Kandy		Tianjin	
	U	S-U	U	S-U	U	S-U	U	S-U	U	S-U	U	S-U
1980s	-	-	56	-	-	-	-	-	-	-	-	-
1990s	46	9.3	78	10			-	-			-	-
Recent	40	9.1	89	15	64	22	77	21	80	21	-	-

U: Urban areas, S-U: Suburban areas, (-) Data is not available

Note: In all cities, over 90% of the water used in the piped supply is from surface water sources.

(2) Sanitation

Urbanisation has occurred very quickly, and therefore, the development of sanitation facilities can often not catch up with the rate of the cities' development. As a result, sanitary conditions in Asian cities tend to be very poor. Beside the very limited cases of central sewer systems available, on-site sanitary facilities such as septic tanks are being mostly used for domestic wastewater. However, their construction and management are very often improper, allowing the discharge of untreated wastewater into the environment. Even direct discharge of wastewater due to the lack of sanitary facilities in the houses has been observed in some cities.

The poor sanitary conditions appear to have caused shallow aquifer contaminations and health-related problems such as communicable diseases. In addition, polluted surface water, which is also commonly observed in some cities, is assumed to contribute to the contamination of groundwater through the interconnection with aquifers. In the case study cities, therefore, there is much room for improvement in the sanitary conditions. The state of sanitation in each case study city is summarised below.

Tianjin
- There are now four central wastewater treatment plants in the city, and two more plants are planned to be built by 2010.
- The total volume of wastewater discharged in the city is estimated to be around 1.7 million tons per day, and only 40% of the discharge is currently treated in the city.
- Some of the untreated wastewater is being used for irrigation, threatening the contamination of soil and shallow aquifers in some areas, such as Wuqing County where the use of wastewater for agriculture has been the practice for a long time.

Bandung
- There is one centralized wastewater treatment plant in Bandung Metropolitan area, and about 16% of the people being served with the system.
- Beside the central system, around 36% of people are served by on-site sanitary systems for domestic wastewater. However, on site sanitary system such as septic tanks properly installed or constructed is estimated to be only 20% overall. Direct discharge of domestic wastewater into rivers is suspected to be pervasive.

Colombo
- There is one central sewer collection system available in the limited urban area.
- Besides one treatment plant, septic tanks with a soakage pit system are used. The facility types of such sanitation in the Colombo district include: water seals (77.4%), pour flush (17.2%), pits (1.9%) and others (0.7%). In the Gampaha district, the figures are water seals (77.7%), pour flush (13.9%), pits (4.9%) and others (0.5%).
- Since the water table in many areas around Colombo is very shallow, a high degree of groundwater contamination with untreated wastewater is suspected.

Kandy
- There is no central sewer system in the Kandy district, and domestic wastewater is treated by on-site treatment systems.
- The facility types of sanitation in the Kandy district include: water seals (65.5%), pour flush (17.7%), pits (12.1%) and others (0.8%). Around 2% of households do not have toilet facilities at all.
- Due to the low water table especially in the centre of the city, the open discharge of toilet waste is suspected of being very high.

Bangkok
- Currently, ten central wastewater treatment projects are being implemented by the Bangkok Metropolitan

Administration, with a potential total capacity of one million cubic meters per day of wastewater treatment by 2000. By 2005, seven treatment plans have finished construction, and five treatment plants located within Bangkok city are in operation, with the coverage ratio by population being about 26 % in the city

- All private properties are required to have some form of wastewater treatment facility. Houses that are not connected to the central sewer systems must at the least install septic tanks for sanitation.
- Wastewater from such activities as bathing and washing are allowed to go directly into the drains without pre-treatment.

HCMC

- There is no central wastewater treatment plant at present.
- The quality of installed septic tanks, which are the main sanitary facility in the city, is very poor in some districts. More than 70% of the septic tanks installed are reported to be improperly constructed or managed in two districts in the city, and are not lined with concrete. In two other districts, it is estimated that nearly 20% of households have no sanitary facilities.
- The direct discharge of human waste into ponds is also observed in some cases.
- The city's drainage system is a combined system that collects both storm water and wastewater. The collected wastewater is directly discharged into canals.
- The canals that receive untreated wastewater appear to be highly polluted.

4. Policy Responses, Possible Management Options, and Future Challenges

4-1. Management Options to Groundwater Resources (quantity control)

An objective of groundwater management in terms of quantity is to use the resource to the extent of the recharging capacity of the aquifer. It is difficult, however, to explicitly identify the susceptibility of the resource and define the extent to which we can use it because of the complexity of groundwater systems. In addition, the state of groundwater tends to change in terms of both quality and quantity in response to social, economical and environmental changes. In particular, urbanization and globalization bring continuous change to cities in multifarious respects, and this can significantly impact the state of groundwater in cities. For example, a reduction of recharging areas following the expansion of urban areas greatly impacts the availability of groundwater. In cities, the mix of different beneficial uses is more prevalent than in rural areas, e.g. public/private domestic water supply, industrial use, commercial use and agricultural use. Growing water demands for such different beneficial uses can dramatically and intricately impact the state of groundwater. To deal with these changes, groundwater management in cities should be flexible and should incorporate medium and long-term perspectives.

Figure II-10 shows the four options of conventional groundwater management measures that will contribute to the control of groundwater abstraction and therefore the conservation of the resource. Each option can be solely introduced, but it is desirable the options should be optimally integrated in consideration of local needs and conditions.

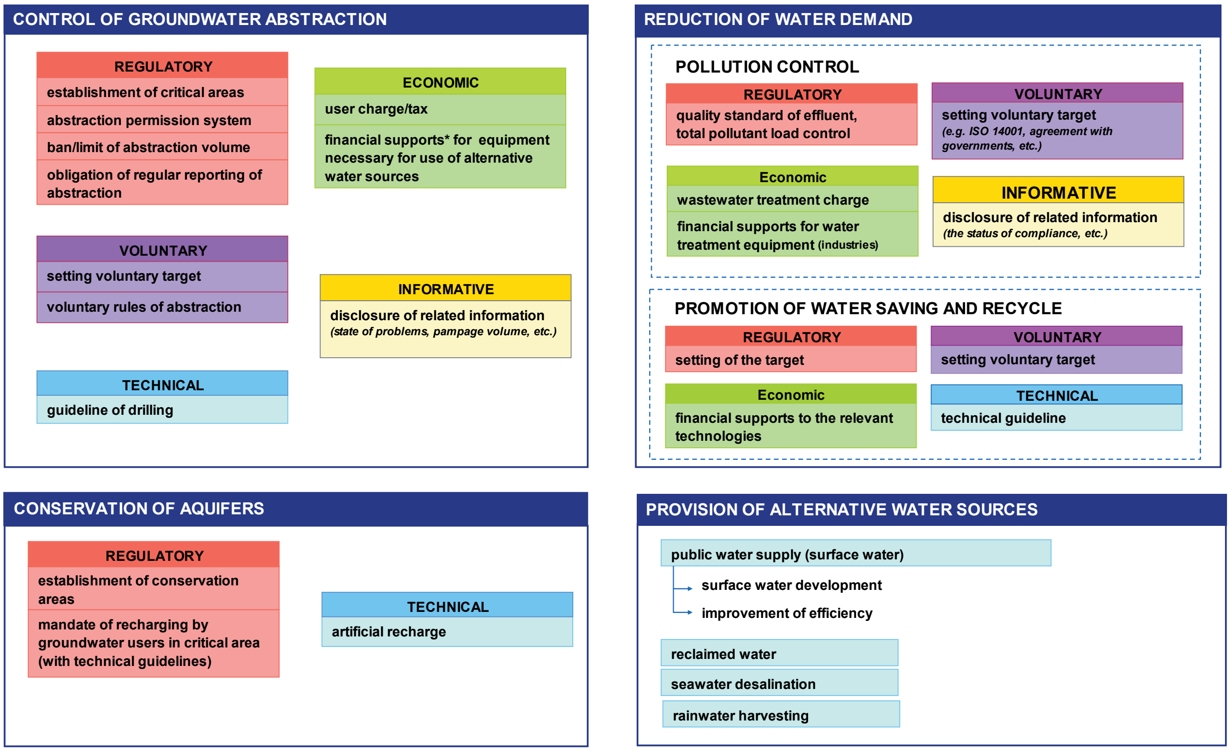


Figure II-10. Areas and Measures of Groundwater Management (quantity control)

The first option, control of groundwater abstraction is the fundamental of the groundwater management, and in case study cities that have already taken some measures to control groundwater abstraction, some measures have been already implemented. But when it comes to implementation, the effectiveness of groundwater management in particular regulation of groundwater pumpage seems to depend on the ability of monitoring of the actual pampage and the availability of alternative water sources. Economic instruments such as groundwater user charge can work well but it is difficult to increase the groundwater charge rapidly because it may damage livelihoods of local people, especially the poor.

The second option aims to reduction of water demands, including groundwater demands by introducing incentives or disincentives of water use. This option will contribute to not only abatement of groundwater problems but also to the conservation of water resources. In addition to promotion of water saving and recycling practices, strengthening of pollution control measures can lead water users to water conservation practices because the cost of wastewater treatment can be reduced by minimization of water inputs.

The third option is the increase of recharging capacity by conservation of aquifer. In the urban context, this option should be fully considered because depletion and deterioration of recharging area is very serious.

The fourth option is the provision of other water source of groundwater. This option is often combined with the first option - control of groundwater abstraction. Instead of limit or ban of groundwater abstraction, other water sources would be provided to groundwater users. In most cases, extended public water supply coverage using surface water as its source is the common measures taken. However, strengthening the capacity of public water supply often require the new development of infrastructure and substantial funds. Socioeconomic and environmental impacts should be also considered before taking this option.

Generally, in the area where overexploitation of groundwater causes serious groundwater problems, combination of the first and fourth option, control of groundwater abstraction and provision of alternative resources, play the central roles of the management.

(1) Policy measures to control groundwater abstraction in case study cities

Table II-13 summarizes the policy measures taken in case study cities, except Colombo and Kandy which do not have actual measures in place yet. As a reference case, the policy measures taken in Osaka, Japan were referred to in the table. In the following section, groundwater management elements will be summarized.

Table II - 13. Summary of Groundwater Management Measures in Case Study Cities [a, b]

City		Tianjin	Bandung	Bangkok	HCMC	Osaka
problems caused by overexploitation		drawdown land subsidence saltwater intrusion	drawdown land subsidence for certain area	drawdown land subsidence saltwater intrusion	Not identifiedt	(in 1950-60s) draw down land subsidence saltwater intrusion
legal status of groundwater		public	public	State-owned[c]	public	Private[d]
Leading institutions of groundwater management in the city		Municipal Gov.	City or Regency with technical recommendation from Provincial Government of West Java	Department of Groundwater Resources, MONRE	City Government	Municipal Gov. (prefecture)
type of measures	**measures**					
regulatory	laws/regulations of regarding groundwater management	Temporary Regulation on Groundwater Resource Management in Tianjin (1987)	Act No.11/1974 and its Amendment No.7/2004 on water resources, West Java Regulation No.16/2001, Local Government Regulation etc.	Groundwater Act (1977, latest amendment 2003)	-----	Industrial Water Law Building Water Law local ordinances
	zoning (control area)		- critical areas - vulnerable areas - safe areas	-groundwater areas, -critical groundwater zones	-----	control areas designated by laws and regulations
	restriction of abstraction			(in critical zones especially those covered by public water supply systems)		(in the areas designated by laws and regulations)
	industrial use	yes	yes	yes	-----	yes
	commercial use	yes	yes	yes	-----	yes
	domestic use	yes	yes	yes	-----	yes
	agricultural use	no	yes	yes	-----	-----
	registration and/or license of groundwater use	yes	yes	yes	-----	yes
	construction of new wells	permission by public authorities	should comply with technical guidelines	permission by public authorities	-----	permission (based on the laws and regulations)
	quality standards	-----	-----	yes	-----	yes
	fines to violation	yes	yes	yes	-----	yes
economic	charge of groundwater use	groundwater fee	groundwater user tax		-----	-----
	note	agricultural use including drinking water for farmers is exempted. extra charge for additional use to planned volume (re. regulations on urban water saving of Tianjin)	tax is calculated using index values given by the regulations	discount of charge in the areas without public water supply, including exemption of crop cultivation and small use for animal farming	-----	Wastewater treatment charge could contribute to groundwater abstraction control by promote rationalization of water use, in particular in industries
	trade of water use rights	-----	------	-----	-----	-----

Table II - 13. Continued

type of measures	measures	Tianjin	Bandung	Bangkok	HCMC	Osaka
informative	reporting	-----	monthly report for groundwater pumpage and level Governor's Decree on technical guidance	annual report books/booklets about groundwater laws and groundwater conservation Criteria and guidelines have been set through Ministerial Regulations and Notifications groundwater drilling license and training system	-----	annual report
supporting	technical guidelines for groundwater abstraction & use					-----
supporting	financial assistance to apply technologies					
supporting	supply of other water sources	- surface water by inter-basin transfer -seawater desalination -reclaimed water use	surface water through public water supply (limited)	surface water by public water supply scheme (extending)	-----	surface water by a new water supply scheme exclusive for industrial sector
technical	groundwater recharge	obligation of recharge by well users (hot water in bedrock)	-----	-----	-----	-----
monitoring	regular monitoring	groundwater level land subsidence	groundwater level groundwater pumpage	groundwater level	groundwater level	
monitoring	quality monitoring	if any changes are observed by well users	yes when user will be extending registration	with monitoring	no regular monitoring	

Note: a. The information in this table was based on the case study report of respective cities.

b. Information of Colombo and Kandy was not referred in this table because there are no specific policy responses in these cities.

c. In Thailand, at present no specific legal instrument exists in any law that clearly establishes the ownership on water of that specifies to whom water belongs. Nonetheless, in accordance with generally accepted principles of law and special legal provisions in various acts the ownership of all water resources is vested in the State. (JICA et al., 1999)

d. In Japan, there are no provisions regarding rights regarding groundwater, but it is regarded that the land owners have an exclusive right of groundwater use.

(2) Policy responses and their effectiveness in Tianjin, Bangkok, and Bandung

(a)Tainjin

Measures taken

Groundwater management in Tianjin consisted of three major elements, namely (a) the transfer of water from other basins, as an alternative water groundwater source, (b) restrictions on groundwater abstraction through regulatory measures, and (c) the imposition of a groundwater charge. In addition to these management elements, it is notable that the city includes water rationalization aspects (water saving, reuse and recycling) in groundwater management, following its policy of water management.

• **Transfer of water from other basins**

A water transfer project from the Luan River, located 160km north of Tianjin, started in the 1970s and ended in 1983. Water transferred from the Yellow River took place when the Luan River failed to supply enough water. The water supply of the urban area of Tianjin was shifted entirely from Luan River to the Yellow River Basin since November 2004.

• **Restriction of groundwater abstraction**

"Temporary Measures for Groundwater Management in Tianjin" were introduced in 1987 to control groundwater abstraction in the city. Under the regulations, groundwater users are required to obtain permission for abstraction from the municipal authorities designated by the regulation. With the regulations, groundwater pumping was prohibited in urban districts in principle. But while enforcement is very strict in so-called "land subsidence areas" where groundwater problems were observed, namely urban areas, Tanggu district, Hangu district, Dagang district, and the lower reaches of the Hai River. However, the enforcement is rather weak in other districts. In addition, agricultural use of groundwater is not restricted, even though this sector is currently the biggest consumer of the resource.

- **Groundwater charge*[1]**

Together with regulations on abstraction, groundwater charges have been imposed since 1987, based on the "Regulations on Levying Groundwater Fees in Tianjin". Agricultural use, drinking uses for farmers, and applications in oil fields were exempted from the charges. As seen in table II-14, groundwater charges have been revised three times. Groundwater charges more than tripled in areas with tap water supply in 2002, while the tap water supply charge was also increased to 3.6 yuan/m^3 from 2.2 yuan/m^3. The groundwater charge is still lower than the cost of tap water.

A notable feature of the groundwater charge in Tianjin is the progressive charge applied to the excess volume of planned water use amount based on the Regulations on Urban Water Saving in Tianjin. In this water-stressed city, water saving considerations are accommodated in the charging scheme.

Table II-14. Groundwater Charge in Tianjin

	Township enterprises	Petrochemical enterprises	Other enterprises
1987	0.05	0.12	0.0968
1988	0.50	0.50	0.50
	Areas with public water supply		Areas without public water supply
2002	1.90		1.30

BoxII-3. Water Rationalization in Tianjin

The tenth Five-Year Plan of National Economic and Social Development in 2001 stressed the sustainable use of water resources, through artificial rainfall, reclaimed water, and seawater desalination. Tianjin introduced these water conservation practices into its policy. For example, the Tianjin Water Saving Regulation was introduced in 2002, under which it is mandatory to install water recycling facilities in the building under a reclaimed water utilization plan. The Regulation on Drainage Water and Reclaimed Water in Tianjin (2003) encouraged reclaimed water use for miscellaneous uses such as greenbelt, toilet flushing, vehicle washing, and construction, cooling and washing in industries, as well as environmental use for landscaping. Rationalization of water use contributes not only to water conservation but also to reduced groundwater use.

Effectiveness of the Control Measures

The measures taken in Tianjin have helped control groundwater abstraction in the five subsidence areas. Figure II-11 shows that groundwater abstraction volume in the urban district of the city fell dramatically in the 1980s. The water transfer project from the Laun River seemed to contribute to the decrease between 1981 and 1985. Restrictions on groundwater abstraction and the groundwater fee introduced in 1987 supported the continuous fall in abstraction volume in the 1980s.

Today, groundwater problems are easing in the area where control measures were intensively introduced, but other areas where irrigation farming is practiced face a continued fall in groundwater level and resulting land subsidence. The key to groundwater management in the city in the future is controlling groundwater use in the agricultural sector, which is currently still exempt from strict control.

*1. 1 Chinese Yuan = 0.12447 USD (as of 7 March 2006)

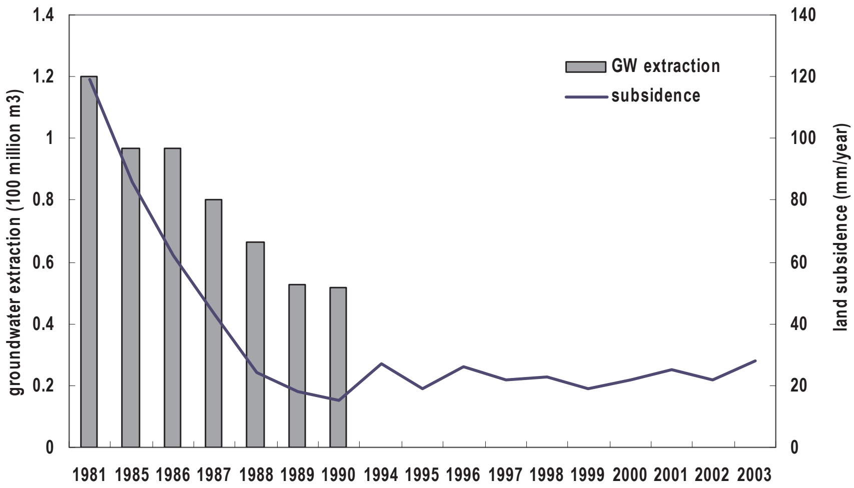


Figure II-11. Groundwater Abstraction and Subsidence in the Urban District of Tianjin

Note: The data of groundwater abstraction after 1994 is not available.

(b) Bandung

Bandung faces a rapid drawdown of the water table and a resultant decrease in well yield. There is a set of national and local legislation for groundwater conservation. The main components of the management are regulation of groundwater abstraction and charges for groundwater abstraction.

Measures taken

- **Regulation of groundwater abstraction**
  Under the provincial and municipal regulations, groundwater should be abstracted with the permission of public authorities. However, enforcement is not especially strict and groundwater abstraction cannot be properly controlled. It is believed that illegal pumping is fairly widespread. Groundwater use for public water supply was supposed to be prohibited, but constraints on the availability of other water resources have forced the public water supply company to keep using groundwater, although the abstraction volume has decreased. These are areas under the regulation that need the attention of groundwater managers.

- **Groundwater Use Tax*2**
  A groundwater use tax was introduced to the city in 1997. The tax rate was calculated based on given values for the three types of index, namely a natural resource component (water abstraction zone, water quality, availability of alternative water resources, and type of groundwater), a recovery compensation component (use and abstraction volume), and a raw water price (fixed amount/m^3). The calculation is rather complex, but based on the price of groundwater calculated under the rule, groundwater is still cheaper than surface water. For example, the price of groundwater abstraction with 3,000-5,000 m^3 is Rp 3,138 m^3, but tap water supply from the public water supply in the Bandung Municipality for industries ranges from 4,725 - 9,600/m^3.

Box II-4. Impact of Decentralization and Groundwater Management

Following the decentralization policy of the Indonesian Government, groundwater management authority and the charging of the groundwater abstraction tax was transferred from the provincial government to municipal governments in 1999 and 2000, respectively. However, decentralization seemed to result in poor management of groundwater, such as over the excessive issuing of abstraction permission, partly because of the lack of proper understanding of the resource of the municipal government. In 2004, authority for the management of groundwater resource was sent back to the provincial government, but it is still necessary to coordinate provincial and municipal government responsibility as well as the contents of regulations issued by the respective parties.

Effectiveness of the Control Measures

Despite the bolstering of the groundwater management scheme, management could not be clearly seen to be effective in the city. One reason for the weakness is the lack of alternative water resources in the city. The provincial government is now planning to develop small-scale dam construction, although it is doubtful that enough water can be supplied to meet competing water

*2. 1 Indonesian Rupiah = 0.000109 USD (as of 7 March 2006) demands for different beneficial uses. There are some environmental concerns in the development of new water infrastructure. Considering the sharp decrease in groundwater use in 1997 when the city was caught up in the Asian financial crisis, it is obvious that control of groundwater use in industries is key to groundwater management. Consequently, in addition to providing alternative resources or taking on the social and environmental risk of new surface water development, the rationalization of water use in industries should be encouraged to minimize groundwater use.

(c) Bangkok

Measures taken

- **Restriction of groundwater use by regulation**
  The Groundwater Act was enforce in 1987 and amended twice until 2003. The law designated groundwater control zones where more intensive control is necessary. Under the Act, the permission of the public authority is required for drilling, groundwater use, and abandonment of wells. In the critical zones, new well construction was basically prohibited in areas with an adequate public water supply in 1983. The Act allows for special treatment of groundwater users in areas where the public water supply is not available. Therefore, the effectiveness of the Act is closely related to the scope of the public water supply system. Because of the extension of the public water supply scheme, enforcement of the Act has begun to strengthen recently.

- **Extension of public water supply**
  Facing groundwater problems, groundwater exploitation for the public water supply scheme was to be prohibited by 1987 based on the Mitigation of the Groundwater Crisis and Land Subsidence in Bangkok Metropolis in 1993. The attempt to phase out groundwater was not initially successful, but since 1996 municipal water use fell dramatically with the development of infrastructure.

  By 2004, coverage of water supply by public water supply in metropolitan Bangkok reached 90 percent of total coverage, and enforcement of groundwater pumping regulations was strengthened.

- **Charging for groundwater use*[3]**
  Charges for the use of groundwater started in Bangkok in 1985. From 2000 to 2003, the groundwater use charge has been increased—in stages but still dramatically—from 3.5 to 8.5Bt/m^3. The current groundwater price is lower than the tariff on the public water supply*[4] because the Groundwater Act has a provision stipulating that the rate for groundwater charges should not exceed the maximum rate of tap water supply.

  In addition to charges for groundwater use, a new charging scheme called the Groundwater Preservation Charge was imposed on groundwater users in the critical zone in 2004. The charge will gradually be increased from 4 Bt/m^3 in 2004 to 8.5 Bt/m^3 in 2006. The sum of charges for groundwater use and preservation will be close to the tariff for public water supply, which will mean a weakening of the pricing edge that groundwater has over public water supply. Revenue from groundwater preservation charges will be sent to the groundwater preservation fund, which in turn is allocated to activities and research related to groundwater conservation. There are thus great expectations that the charges will enable better control over groundwater abstraction and will also bolster groundwater conservation efforts in different sectors.

Effectiveness of the Control Measures

As figure II-12, groundwater abstraction tended to increase until 2000 in Bangkok, multifarious groundwater control measures notwithstanding. Starting 2000, however, extensive public water supply and rising charges for groundwater use led to a decrease in groundwater abstraction, and the introduction of the groundwater preservation charge will only aid this trend.

However, interviews with several industries during the study shows that there are some doubts about the reliability of public water supply in terms of quality and stability. The reliability of pubic water supply as an alternative to groundwater should be a focus. Another concern is the availability of surface water resources. Tension over surface water in Bangkok is also very high and in dry years the dependence on groundwater may increase because there are no alternatives. It is necessary to consider how groundwater management should adopt to this unusual situation.

*3. 1 Thai Baht = 0.0258 USD (as of 7 March 2006)
*4. The tariff for pubic water supply (by the Metropolitan Water Authority) in metropolitan Bangkok in 1999 ranges from 8.8 to 14.45 Bt/m^3 for domestic use.

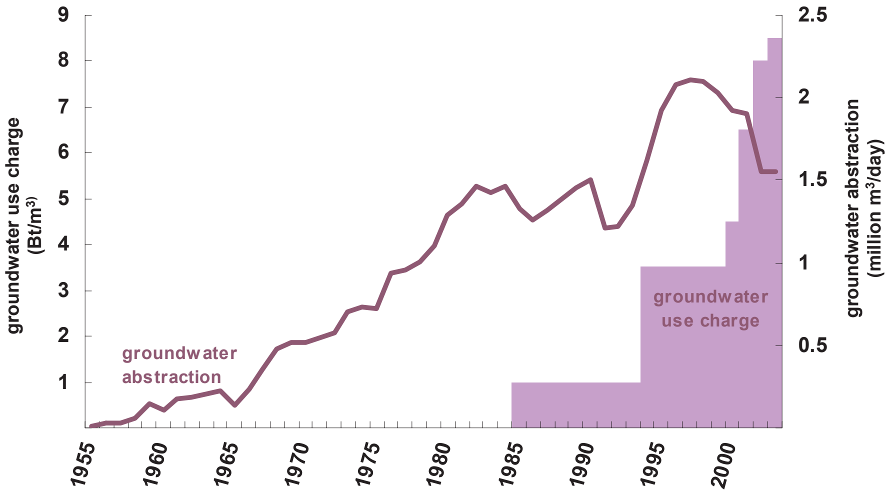


Figure II-12. Groundwater Abstraction Volume and Charges for Use in Bangkok

Note: Charges for groundwater use increased in stages each quarter. The rate here is the rate of December of each year

(3) Implementation Barriers and Challenges Identified

In three cities, Tianjin, Bandung an Bangkok, the following barriers and challenges of implementation were identified.

(a) Deficiency of the existing measures

- Insufficient provision of surface water as an alternative resource
- Lower tariffs for groundwater than for tap water
- Lack of shallow aquifer regulations
- Weak enforcement of existing water regulations
- Exemptions from controls and charges covering agricultural groundwater use.
- Reduced consideration of groundwater conservation in urban planning.
- Weak integration between groundwater and surface water management
- Improper maintenance of monitoring and metering systems

(b) Institutional problems

- Bolstering of awareness of relevant institutions to promote groundwater management
- Coordination of government authorities in charge of groundwater management
- Deficiency of current groundwater management in the city which does not properly reflect socioeconomic changes.

(c) Others

- Lack of financial resources
- Lack of human resources
- Lack of public awareness of groundwater problems and obligations stipulated by the regulations
- Lack of communication among stakeholders

(4) Lessons from Groundwater Management in Osaka

Land subsidence as a resultant of excessive groundwater use emerged as a social problem in Japan during the period of industrialization from the 1950s to 1970s. In the city of Osaka, which faced a severe drawdown of the groundwater level and land subsidence in the 1950s and 1960s, intensive measures were able to control groundwater abstraction and alleviate the groundwater problems. The key components of groundwater management in Osaka are (a) strict control of groundwater abstraction, (b) provision of surface water to the industrial sector as an alternative to groundwater by developing a new water supply scheme for industries called the Industrial Water Supply Works (IWSW), and (c) financial support for facilities and equipment for water saving.

The strict control of groundwater abstraction was imposed by national laws on industrial and building*[5] applications that were the major groundwater uses in the city. Under the Industrial Water Law introduced in 1956 and amended in 1967, groundwater abstraction was restricted by well-size and depth in the areas designated

*5. Building use referred to groundwater use in commercial buildings and large apartments.

PART II

by the law. In the case of Osaka, use of almost all wells was prohibited under the law. The conditions determining abstraction control under the law was the water supply from IWSW. Osaka formed the IWSW to cover all law-designated areas step by step by 1968, and succeeded in reducing groundwater abstraction before 1970 in the industrial sector, as figure II-13 shows.

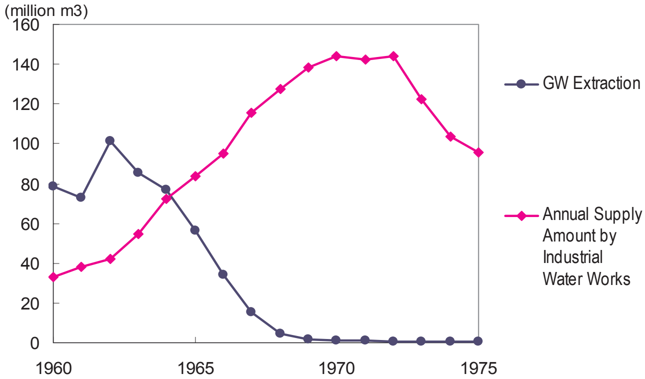


Figure II-13. Transfer of Groundwater Use to Industrial Water Supply Works in Osaka

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

For buildings that primarily used groundwater for cooling, it was effective to provide financial support for the introduction of water saving technologies such as a cooling tower. The local government negotiated over time with the private sector to stop groundwater abstraction.

Intensive control of groundwater abstraction succeeded in attenuating groundwater problems in the city, but it was pointed out that control measures were introduced according to administrative boundaries rather than based on the groundwater basin. Consequently, responses to the problems in Higashi-Osaka area—located in the same groundwater basin but in a different administrative boundary—were delayed.

Long-term impacts of the policy measures

After more than 50 years, groundwater management in the city faces a new paradigm. The successful control measures in Osaka have now given rise to other issues, including:

- Increase in the groundwater level because of strict controls on groundwater abstraction, with the potential to damage building infrastructure that was designed for a lower groundwater level and increase the risk of liquidification should a major earthquake strike.
- Financial difficulties confronting IWSW because of declining industrial water demands as a result of water rationalization practices in the sector.
- Strict regulations and the fear of the potential risk of land subsidence hindering the optimal use of groundwater after the recovery of the groundwater level.

In other cities in Japan, the effectiveness of the combination of two measures to control industrial groundwater demand (restriction and provision of surface water by IWSW) was not as clear as seen in Osaka because of the delay in supply by IWSWs and/or a rapid change in water use by industry.

Also, in other cities where groundwater control is not as especially strict as it is in Osaka, groundwater began to be increasingly used in shopping complexes and hospitals as part of risk management in unusual events and as a cost saving exercise. In most cases, they are large consumers of the public water supply, and it is therefore now seen as important to reduce their demand on public water supply with the application of groundwater use.

Box. II-5. Rationalization of Water use in Industries

In Japan, rationalization of water use in industries has grown rapidly since the 1970s, as shown in figure II-14. Reasons for this include:

- The water tariff of IWSW was higher than the cost of groundwater extraction.
- Water pollution control was strengthened in the 1970s and industries should comply with water quality standards for effluent from factories. To reduce the cost of wastewater treatment, industries tried to limit water inputs and promote water recycling and reuse in their production process.
- A wastewater treatment charge began to be imposed and so the minimization of wastewater needs to cut the cost of wastewater treatment charge.
- Water rationalization in industries was included as an important element of water management policy in Japan to meet the increase in the need for different beneficial use. To encourage water rationalization, the government should provide financial support to industries to introduce water recycling and reuse technologies.

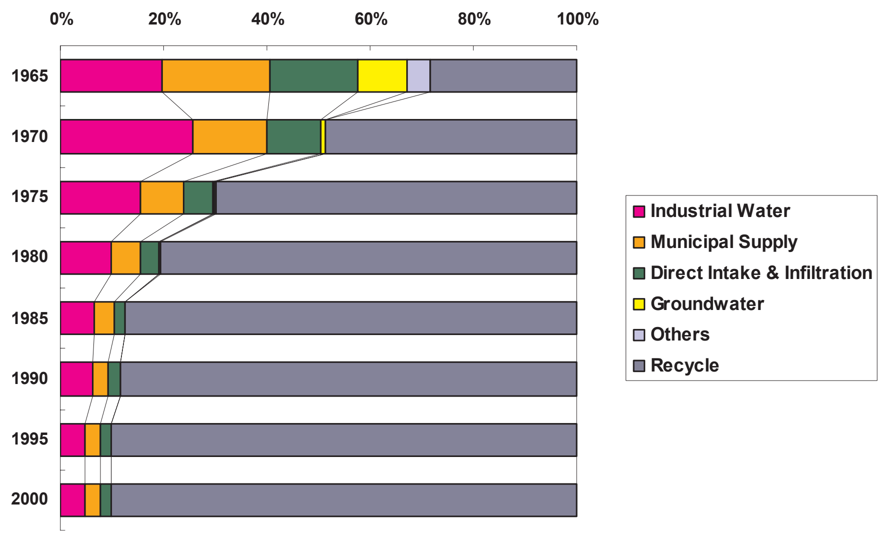


Figure II-14. Freshwater Supply for the Industrial Sector, by Source (Osaka City)

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.

Lessons

A long-term review of groundwater management in Osaka and other Japanese cities offers the following lessons:

- The combination of strict control of groundwater abstraction and the provision of alternative water resources can alleviate emergent groundwater problems, when alternative water resources can be provided in a timely manner.
- Financial support for facility application is required for compliance with groundwater control regulations.
- Strict groundwater control can result in an undesirable increase in groundwater level, and should therefore be reviewed and revised regularly.
- An infrastructure development plan for alternative water resources should take into careful consideration the possibility of water rationalization in certain industries. New infrastructure development may take time to provide a water supply and may have an adverse impact on the environment.
- Water rationalization in industries is a very promising tool for reducing groundwater abstraction by minimizing water use. It is therefore better to encourage water rationalization as a first priority of groundwater management, in cooperation with the management of other water sources.

(5) Challenges of Groundwater Management in Asian Cities

Reviewing the case study cities, the state of groundwater management varies depending on the magnitude of the problems confronting each city. Bangkok and Tianjin have been tackling a drawdown of the groundwater level and the resultant land subsidence by controlling groundwater abstraction for more than two decades. They are seeing positive signs. In Bandung, groundwater abstraction control has strengthened since 1990, a period during which the city has experienced rapid economic growth, but the city is still struggling to control abstraction. In cities where groundwater problems have not been identified, such as HCMC, Colombo and Kandy, there are no specific measures to control groundwater abstraction to date, although environmental strategies of HCMC expresses concern about the over-exploitation of resources. This fact shows that the case study cities have begun to adopt practical controls when groundwater problems have been socially identified. But considering that groundwater problems take longer to correct or can indeed be irreversible, such as the problem of land subsidence, when it comes to the susceptibility of groundwater resources and groundwater control measures should be exercised even before the problems are identified.

To achieve sound groundwater management, water rationalization needs to be prioritized, rather than simply placing an emphasis on the provision of an alternative with new water source development. An incremental cost for groundwater use, including a wastewater treatment fee, can work effectively to encourage water rationalization, as we have seen in the case studies.

Groundwater management in Asian cities is still supply oriented, however, and control of increasing demand receives less consideration in groundwater management. The rationalization of water use is often dealt with in other realms of water management, although the integration of the management of groundwater and other areas of water resources is repeatedly emphasized in the framework of integrated water resource management. Groundwater management should be better highlighted in comprehensive water management plans for a more sustainable future for water resources in the region. Confusion or lack of coordination on the part of the institutions in charge of groundwater, financial difficulties, insufficient human resources, or a lack of public awareness are common hurdles to groundwater conservation efforts. Reliable data is also a prerequisite of sound management. Monitoring the state of groundwater in terms of quantity and quality, it is essential to obtain reliable data on the abstraction volume and purpose of use where possible, even if it is difficult to obtain data of a decentralized resource.

4-2. Groundwater Management (quality-wise)

(1) Current Status

If groundwater is utilized for drinking as well as other domestic purposes, groundwater contamination can potentially pose serious threats to human health. Apart from the health risks, it is difficult to restore contaminated aquifers due to the prohibitive costs and technological feasibility. Therefore, it is imperative to improve quality management schemes and policy implementation.

However, the case studies revealed that, with a few exceptions, management of groundwater quality tends to be lacking or underdeveloped compared to the management of quantity. For example, groundwater quality monitoring—an essential component of quality management—is not systematically implemented in most of the cities, and it is deficient in its coverage of monitored pollutants. In fact, the case studies show that coverage of monitored pollutants differs considerably across the cities. In addition, the current quality standards particularly targeting groundwater are still immature in most cases, and it does not fully reflect suspected groundwater pollutants. The insufficient quality management and poor policy implementation is attributed to various types of barriers and obstacles, such as deficient human resources in implementation, low awareness, and lack of financial resources. Overcoming these obstacles is the key to improvement of groundwater quality management and effective policy implementations.

(2) Measures and technologies for coping with aquifer contamination

Complexities exist with regards to aquifer contamination mechanisms. First, groundwater contamination is often subject to a time lag in response to original contaminant loads. Sometimes, it could take decades before contaminants reach an aquifer and pollute it. The extent of the time lag actually depends on many factors, including hydrogeological conditions, precipitation, and saturation levels. Second, the impact of contaminant release also depends on various factors such as the thickness and soil type of the topsoil layers, the depth and volume of aquifers, direction of water flow, its connection to surface water bodies, and meteorological conditions. These complexities make it difficult to judge an appropriate timing and effectiveness of taking policy measures. However, this fact doesn't support the delay of taking policy measures to tackle groundwater contamination.

Table II-15 summarizes groundwater pollutants that are particularly relevant to the case study areas, examples of technologies to remove the pollutants which are observed in the case study cities, and possible preventive measures applicable to each type of pollution. Since each pollutant has its own probable causes, the countermeasures for aquifer and soil contamination should be formulated in accordance with each pollutant. For example, quite a high level of coliform, as observed in Bandung, and HCMC, may be due to effluent from poor on-site sanitary systems, such as septic tanks and improperly constructed dug wells. Thus, improvement of on-site sanitary systems and proper construction or maintenance of dug wells is of vital importance as a preventive measure. In addition to these causes of pollution, deteriorated surface water quality, which is often observed in the urban cities in Asia, can be a cause of groundwater contamination through the interrelationships. Since surface water quality deterioration is serious in many Asian cities, the quality control of surface water bodies should be also considered part of groundwater quality management. This indicates that dual perspectives of both surface water and groundwater in quality management are crucial in some cases. As far as naturally occurring pollutants are concerned, it is important to investigate the hydrogeological conditions before using groundwater, particularly for drinking purposes, in order to avoid possible health risks.

Table II-15. Matrix of Pollutants, Typical Pollution Causes, Removal Technologies and Preventive Measures

Pollutant	Typical causes	Example of removal technologies observed in case study cities	Preventive measures (specific to pollutant)
Fluorine	- Naturally occurring	- Adsorption (e.g. Activated Carbon) - Aluminum precipitation	(Conducting hydrogeological studies before water use)
Metals (e.g. manganese)	- Naturally occurring	- Aeration & sedimentation - Adsorption - Filtration	(Conducting hydrogeological studies before water use)
Heavy metals (e.g. cadmium)	- Discharge from industry - Leakage from landfill	- Treatment of soils by physical solidifications - Treatment of soils by chemical reactions	- Regulation on industrial waste discharge - Re-location of industry
Nitrate	- Fertilizer for agriculture - Sewer effluent, livestock waste effluent	- Ion-exchange method - Biological methods	- Reduction of fertilizer consumption - Improvement of sanitary systems
VOCs (e.g trichloroethylene)	- Discharge and spills from industries (e.g. Semi-conductor, metal industry)	- Excavation of soils - Bioremediation of soils	- Re-location of industry - Regulation on industrial wastewater discharge
Coliform	- Sewer effluent, livestock waste effluent	- Boiling - Disinfection methods (e.g. Chlorination, Ozonation, UV)	- Maintenance of dug wells - Keeping proper distance between wells and latrines - Improvement of sanitary systems
Salinity (chloride)	- Salt water intrusion - Wastewater use for irrigation - Sewer effluent	- Desalinization methods (e.g. Reverse Osmosis, Distillation)	- Stopping over-pumping - Groundwater recharging - Proper handling of sewer effluent

In addition to the preventive measures to be adopted in accordance with each pollutant, there are some measures that can, in theory, be adapted to more than two pollutants, such as a penalty system for industries that illegally discharged pollutants or fail to comply with effluent standards, and economic instruments, such as charging system. It should be noted, however, that these measures tend to be difficult to implement. A charging system for pollutants of aquifers is now being implemented in some European countries. Yet this type of economic instrument would not be feasible to implement in most developing countries under current socio-economic conditions. Other common types of measures would include the following.

- Regulations and bans on wastewater and solid waste discharge from the industrial sector
- Zoning system designating polluted areas
- Penalty system for polluters
- Registration systems for hazardous substances in the industrial sector

Technologies are also available for the remediation of contaminated groundwater and controlling the diffusion of contamination. Various technologies have been actually investigated for remediation of contaminated aquifers and soils. For heavy metal contamination, for example, chemical treatment has been experimented in Japan. Bioremediation technology can be applied to remove pollutants in soils contaminated with VOCs. As far as contamination diffusion control technologies are concerned, physical solidification and chemical reactions for contaminated soils, as well as enclosure techniques using such materials as clays and iron sheets have been developed. Basically, these measures are only applicable in cases of point-source pollution, where the pollution is limited to a relatively small area, while they are not appropriate for diffuse-source cases of pollution. Although physical, chemical, and biological technologies are being developed and made available for the removal of contaminants, they tend to be very costly. Therefore, it is highly important that all efforts should be made to take preventive measures for possible aquifer contamination. On the other hand, there are some readily available measures as well, such as the boiling of water from the wells to eliminate coliform contamination. By raising public awareness, these measures, especially those which are readily available and accessible, would be introduced properly.

It is imperative that the best applicable and feasible options be identified and put into practice, according to the local socio-economic and physical conditions. Most of all, establishing quality standards together with systematic and continuous quality monitoring systems is essential for overall quality management as both are prerequisites for quality management. It is also equally important to identify alternative water resources in case groundwater can no longer be relied on due to the heavy contamination. Some examples of alternative water sources are listed below.

- Transferring groundwater from unpolluted wells
- Developing infrastructures for water supply systems
- Rainwater harvesting
- Surface water transferring
- Utilizing small dams, check dams
- Desalinizing water

(3) Challenge and Future Prospects

Policy implementations for quality management might be hindered due to various types of barriers. For instance, lack of human resource dealing with quality management is considered to be among the main problems in terms of implementation for quality management in many Asian cities. Indeed, the poor human resource actually is hindering effective and systematic monitory system. Therefore, capacity building is urgently required to develop quality management.

Other types of obstacles frequently observed in the Asian cities include the financial deficiencies, limited or scattered information and knowledge regarding groundwater quality, improper institutional arrangement such as overlapping governmental agencies coping with quality monitoring survey, and low public awareness about contamination and associated health risks. Various supports should be provided from outside, especially from countries with experiences and knowledge regarding quality management, in order for the Asian cities to improve the current status for quality management.

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PART III

GROUNDWATER MANAGEMENT IN ASIAN CITIES: Summary of case studies

This section is the compilation of the summary reports of six case studies on groundwater management in seven Asian cities, namely Tianjin, China; Bandung, Indonesia; Colombo and Kandy, Sri Lanka; Bangkok, Thailand; Ho Chi Minh City, Viet Nam; and Osaka, Japan. The case studies, which were conducted by the research partners of the Research on Sustainable Water Management (SWMP), constituted the basis of the recommendations and analysis in the previous section.

Each case study consists of the facts and figures relevant to groundwater resource and its management followed by recommendations for future groundwater management, except the Osaka's case that was studied as a reference. In the process of formulation of recommendations for Tianjin, Bandung, Bangkok, and Ho Chi Minh City, stakeholder meetings were held in each city to hear more diverse views and ideas from the participants with different backgrounds.

Note:
The currency exchange rates of the currency of each country to USD as of 7 March 2006 are:

1 Chinese Yuan = 0.12447 USD
1 Indonesian Rupiah = 0.000109 USD
1 Sri Lanka Rupee = 0.0097 USD
1 Thai Baht = 0.0258 USD
1 Vietnamese Dong = 0.000062USD
1 Japanese Yen = 0.00855 USD

Groundwater Resource Management in Tianjin

Xu He and Zhang Lei

1. Background of the Study Area

1-1. Geographical Location

Tianjin is situated in the Northeast part of the North China's plain. The city is located between 38°33′57″ ~40°14′57″ north latitude and 116°42′05″~118°03′31″ east longitude with its boundary bordering on the Hebei Province and the Capital Beijing. Measured from the centre of the Tianjin, it spaces 137km apart from the Capital Beijing, and Tianjin plays an important role of the capital's east portal.

Tianjin covers a total area of 11,919.7km^2, of which plain occupies 94%, and it runs about 186km in north-south length and about 101.3km in east-west breadth, including 15 districts and 3 counties (figure 2). As for climate, Tianjin lies in the temperate zone with a semi-humid and continental monsoon climate, and is beautiful in sight-seeing within the different seasons.

Figure 1. Geographical Location of Tianjin in China

Figure 2. Administrative Divisions of Tianjin City

1-2. Socio-economic Conditions

In 2003, Tianjin municipality encompassed a permanent population of 10.1130 million averaging a density of 926 people/km^2*. Of the population, 59.37% were in the urban area and 40.63% of households were engaged in agriculture. Its gross domestic product (GDP) was 244.766 billion Yuan in 2002, with per capita GDP of 26,532 Yuan. As for the composition of GDP, secondary industry makes 50% contribution to GDP rise, and tertiary industry is booming in recent years (figure 3). The main products of the municipality include steel, textiles, electronic equipment, and chemicals etc.

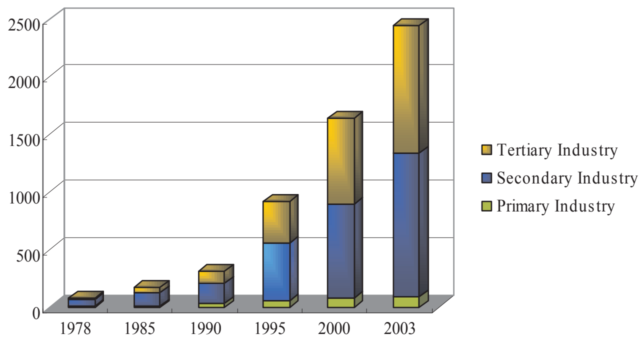

Figure 3. Composition of GDP in Tianjin

Source: Tianjin Statistical Bureau. 1979-2004

Note: primary industry: farming, forestry, animal husbandry, and fishery
Secondary industry: industry and construction
Tertiary industry: service trade and other industries except those mentioned above

*. The population deustiy was culculated based on the registered population.

1-3. Overview of Water Resources

The water resources in Tianjin are composed of surface water, transferred water, reused water, groundwater, and small amounts of seawater (table 1). Based on the 1991-1995 data, the average natural runoff volume is 1.045 billion m^3, incoming volume is 2.168 billion m^3, and the out-flowing volume amount to 1.988 billion m^3. The volume transferred form the Luan River is 1 billion m^3 technically. The total exploitable volume of groundwater is 0.827 billion m^3, 0.702 billion m^3 of which is of suitable water quality, mostly in areas outside the urban center.

Scarcity of water resources in Tianjin is very high, with per capita natural runoff resource volume being about 160m^3, which makes Tianjin enter into the serious water-lack ranks in the whole China. So the state has to transfer the water from the other watersheds, mainly from the Luan River in the adjacent Hebei province, and in emergency, the water from the Yellow River is transtened to the city.

Table 1. Water Supply Reliability in Tianjin

Unit: 100 million m^3

	F=50%	F=75%	F=95%
Surface Water	10.01	6.81	2.41
Transferred Water	7.50	7.50	4.13
Groundwater	7.02	7.02	7.02
Reused Wastewater	1.82	1.82	1.82
Others	0.54	0.54	0.54
Total	26.89	23.69	15.92

Source: Boris Xuhua Fichot. 2001

Note: Frequency=50%: Water inflow reliability for a normal year

Frequency =75%: Water inflow reliability for a moderately dry year

Frequency =95%: Water inflow reliability for a dry year

2. Groundwater Use and its Associated Problems

2-1. Outline of Groundwater

Based on the styles of groundwater, there are two hydro geological areas, which are the mountain areas with crevice water in bedrock and alluvial plain. The alluvial plain can be divided into the interstitial water (water between clay and sand) areas with whole freshwater and the interstitial water areas with deep freshwater, which is covered by salty water on the surface (figure 4).

(1) Mountain areas with crevice water distribute in the north mountain areas of Jixian County, and the area is 727km^2.

(2) The geological fracture zone divides the alluvial plain with two parts, in north of which are whole fresh water areas, and in south are salty water areas.

The exploitation and utilization of groundwater plays an important role in the economic development of Tianjin, and groundwater supply accounts for about 30% in the whole water supply in Tianjin. The groundwater is mainly used in agriculture with above 50% of supplying volume (figure 5).

From the year 1990 to 2002, the average exploitation of groundwater was 748.2 million m^3, and the exploitation rate was up to 90.45%. It is easy to get from the figure 6 that every district had overexploited except Jixian County, Baodi District, Ninghe County and Jinghai County where groundwater had a little surplus (figure 6).

Figure 4. Geographical Demarcation of Groundwater

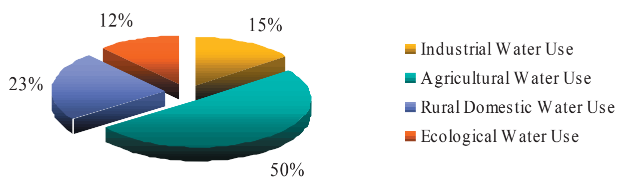

Figure 5. Groundwater Consumption by Beneficial Sectors in 2002

Source: Tianjin Warter Conservacy Reseach Institute 2002

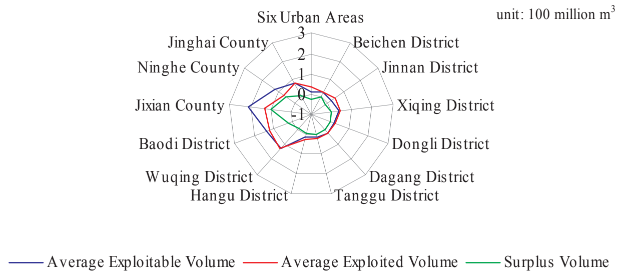

Figure 6. Groundwater Exploitation during 1990 - 2002

Source: Tianjin Planning and Land Resource Bureau 2002

2-2. Overexploitation-induced Problems

(1) Land Subsidence

The main reason of ground subsidence is long-term overexploitation on groundwater. There are five subsidence centers in Tianjin, namely urban areas, Tanggu District, Hangu District, Dagang District, and the industrial areas in lower reaches of Hai River (figure 7).

Figure 7. Land Subsidence in Tianjin

Nowadays, Hanggu District and industrial Areas in Lower Reaches of Hai River still subside because there are no alternative sources available. Contrarily, the ground subsidence in Tanggu District and Urban Areas was alleviated a lot since 1983 with the transferred water available there, just as the figure 8 below shows.

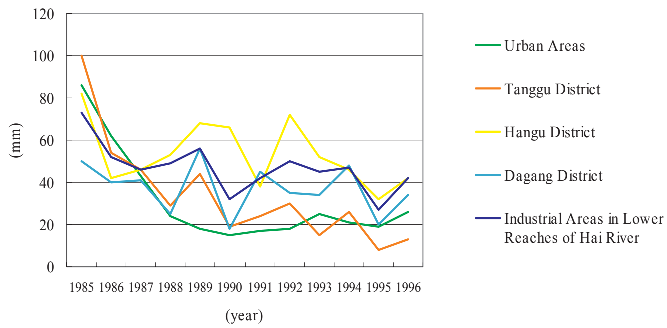

Figure 8. Annual Average Subsidence Volumes in Each Subsidence Center

Sources: Tianjin Water Conservacy Bureau 1997

Note: The monitoring areas were expanded after 1992 in Hangu District and Tanggu District

(2) Groundwater Pollution

It is easy for the shallow groundwater to be polluted by the influence of surface water pollution and the domestic and industrial sewage. Especially in Wuqing County, it has been practicing the sewage irrigation for a long time so that the shallow groundwater is greatly polluted.

There are two reasons that caused the deep groundwater pollution. The one is the poor quality of wells that brings on the mixture of salty water and freshwater, and another is the abandoning wells at will which provide the pollutants and salty water a natural entryway entering into the deep aquifers. The statistics shows that the accumulative total number of abandoned wells is 35,746 up to 1997, hereinto 34,246 wells located in suburbs for agriculture use. Groundwater use for agriculture is not charged for in Tianjin, and there is no measuring device for exploited volume. So the well digging in suburbs is at will and they abandon the wells at will too.

3. Recommendations on Sustainable Groundwater Use

3-1. Policy Recommendations

The management of groundwater began at 1970s. Later, the main regulation on groundwater management, which is still serving at present, was promulgated in 1987, namely *'Temporary Regulation on Groundwater Resource Management in Tianjin'*. Accompanying with this regulation, another supporting regulation came out at the same time, namely *'Regulations on Levying Groundwater Fee in Tianjin'*.

(1) Policy Effectiveness

This main regulations enacted in 1987 on groundwater management have lagged behind the development of the groundwater management. It has been serving nearly two decades, the groundwater itself changed a lot and the Tiajin Municipality changed a lot, while, this regulation has not changed. Obviously, it couldn't catch up with the current groundwater situation. For one reason, it is not all-round and exhaustive that it really set up barriers for groundwater management. For another reason, some articles themselves in regulation have problems. For example, it prescribed that the groundwater for agriculture and oil field was free of charge. In fact, this regulation is more effective on industry and less effective on agriculture. Tianjin Water Conservancy Bureau has been amending the current temporary regulation since 2001 and now has submitted the revised regulation to the government in 2005 waiting for the approval.

(2) Optimal Combination of Different Polices

The optimal combination of different policy measures can maximize the effectiveness of groundwater management.

Legislations
At present, the laws and regulations are not exhaustive and specific not only in Tianjin, but also in China. Take the "Temporary Regulation on Groundwater resource Management" for example, this regulation has been run since 1980s to the present in Tianjin. Times changes, but the regulation is changeless. It is no doubt that this main regulation on groundwater management in Tianjin could not catch up with the development of social-economic conditions and groundwater resource itself. Another example, the state will lay the stress on the river basin management in the future. That is good for the integrated benefits and unified management. However, there are no specific laws and regulations supporting this aim in most river basins (except the Huai River Basin, as mentioned above). Besides, the management of groundwater should keep changing in the course of continuous development of the city.

EIA and SEA
Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) should be implemented at all levels on water resource exploitation and utilization. EIA has been put into practice for years, while SEA just started.

Planning
Groundwater exploitation plan should be consistent with urban planning and be an integral part of urban planning. Urban planning should incorporate measures to conserve groundwater in urban development plan.

Qualification Management on Groundwater Exploitation
It is good for groundwater protection when engineering construction standard of groundwater exploitation and the management on abandoned wells will be standardized. The wells quality depends on the scientific engineering design and higher-level constructer. So the construction organization that will construct or maintain the groundwater project must have the related qualification, and it must not overstep its business scope covered by the qualification.

3-2. Other Recommendations

(1) Supporting Recommendations

Virtual Water Strategy
Basing on the current situation of water scarcity in Tianjin, it is very difficult to supply enough water for large areas of plantation. To solve this conflict, virtual water may works.

Water Saving
Water saving is an effective way to mitigate the conflict between water supply and demand in Tianjin. It's estimated that there is water-saving potential with about 150 million m^3 in Tianjin. While whether water saving can be implemented successfully greatly depends on the basic infrastructure construction, such as rebuilding former water supply facilities to reduce the wasting, and building new facilities supporting the utilization of

reclaimed water and rainwater etc.

Inner Water Transfer from North to South within Tianjin

In the north there is fresh groundwater with exploitable potential, but in the south there is salty water covered with badly overexploitation, focusing on the deep fresh groundwater. So the groundwater resource should be balanced firstly within Tianjin through transferring water from north to south Tianjin.

Alternative Water Sources

- Salty Water Utilization
- Desalted Seawater
- Reclaimed Wastewater
- Rainwater and Flood Utilization
- Transferred Water from North-to-South

(2) Economic Recommendations

Comprehensive Water Fee

As we know, the rational water fee should be the market-oriented. However, it should be necessary as well under the Chinese regime. Water fee should reflect the policy preference on water resources management, which should be the assistant measure to support the policy implementation.

Rationalized Groundwater Fee

At present groundwater fee is obviously low, which badly deviate from water resource value. Groundwater fee for industrial using is far lower than tap water, agricultural and rural domestic use are just levied a nominal fee or enjoy an exemption policy, which has undoubtedly encouraged groundwater exploitation. Thus, it is necessary to set up a rational water fee system to assist water management and comply with the economic rules.

Different Purpose, Different Fee

In addition, water fee should be different between different using purposes. For example, to encourage shallow groundwater and salty water utilization in salty water areas, fees on exploiting these kinds of water should be adjusted lower, and tap water for ground recharging should also be adjusted. Now tap-water fees contain an item of wastewater treatment fee. This fee is 0.6 Yuan per m^3 for domestic user and 1.00 Yuan per m^3 for the other users. The recharging is mainly depending on the tap water, but users who use tap water for recharging has to pay the same as other users. Since they do not generate wastewater, they don't have to pay the fee covering cost of wastewater treatment.

3-3. Recommendations for Overcoming Barriers to Implementation

(1) Rational Institutional Framework

As we know, it's hardly to divide the water effectively into ground part and surface part. Whether or not the groundwater resource can be used rationally has close relationship with rational management of the surface water resources. So we need unify the whole water resources management. While whether or not we can achieve this aim rests with its root, rational institutional framework. The rational framework can be separated into two sections at three main levels (national, river basin, provincial level), namely implementation administration section and supervisory department section for water resources management.

(2) Policy Making

Lack of water source is a big problem in alleviating the exploitation of groundwater process. We have to find the alternative water sources, such as transferred water, recycling water, and desalted seawater and so on. Saving water is still needed at the same time. So, related policies encouraging these activities should be made. For example, shallow freshwater and salty water resources are encouraging to be utilized by the government, while there are no related policies supporting this proposal. On the contrary, some policies block it instead of supporting. Or some preferential treatments should be given, such as preferential water price alike.

(3) Unifying the Water Management

Most of the water-related conflicts in Tianjin, such as water pollution and water scarcity, mostly result from the 'scientific management shortage' rather than 'resource shortage'. In Tianjin, many administrative bodies get involved in the water affairs. Different bodies take charge of different parts. In fact, it is hardly possible to divide water effectively into the ground part and geothermal part, qualitative part and quantitative side with real clarity. So the highly efficient and unified water management system is eagerly needed

(4) Dialogues between Relevant Stakeholders

One of the reasons that the problems will arise in water resources management is the lack of intercommunication between relevant stakeholders. Different information brings on different policy so the conflict comes. Thus it is of great importance to communicate and harmonize between departments and stakeholders.

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PART III

Groundwater Resource Management in Bandung

Setiawan Wangsaatmaja, Arief D. Sutadian, and Maria A. N. Prasetiati

1. Background to the Study

1-1. Administrative Area

The Bandung Basin is often referred to as Bandung Metropolitan. It has seven main tributaries and is one of the biggest river basins on the island of Java. Through the river basin runs its main river namely Citarum. Located in West Java Province, the basin is a plateau encircled by mountains forming a basin. The latitude of the area is 7°19' - 6°24' south and the longitude is 106°51' - 107°51' east. Bandung Basin covers four administrative areas, including two regencies (a part of Bandung and Sumedang) and two cities (Bandung and Cimahi). The total area is 2,340.88 km^2 divided into 77 sub-districts. The basin has many important characteristics. It is a source of drinking water and supports agriculture and fisheries. Its water is the main source for three existing reservoirs that have a total volume of 6,147 million m^3 (Wangsaatmaja 2004). The dams supply water to 300,000 hectares of rice fields and are important hydropower-generated electricity suppliers for the islands of Java and Bali. Figure 1 shows the administrative boundary of Bandung Basin, the case study area.

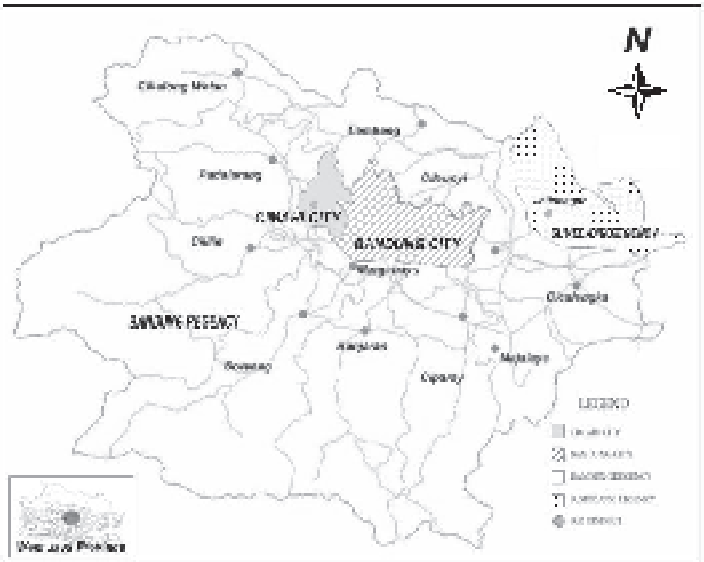


Figure 1. Map of Bandung Basin Based on Administrative Boundary

Source: Wangsaatmaja 2004

1-2. Hydro-Geological Conditions

The groundwater basin in Bandung Metropolitan covers an area of 1,730 km^2. It is bordered in the north by the Lembang Fault, in the west by impermeable tertiary rocks, and a surface water barrier lies in the south and east (Warsono 1985 in Harnandi and Iskandar 1998). The morphology of the study area can be classified into three part. The center of the study area is characterized by a plain morphological unit and covers 25% of the study area, while a hilly morphological unit encircles the plain, accounting for 45% of the study area. Furthermore, volcanic cones are distributed over 20% of the study area. Based on groundwater quantity and quality, the study area is classified into two areas of groundwater potential, namely:

1. Area with moderate groundwater potential in shallow and deep aquifers
2. Area with moderate groundwater potential in shallow aquifers and low potential in deep aquifers

1-3. Socio-economic Conditions

(1) Population

The population of Bandung Metropolitan was 6,080,981 in 2003 and it is predicted to increase to 9,706,363 in 2025. The average density is 2,597 people per km^2. The population growth rate in the Bandung Basin ranged from 1.74% to 3.7% in 2003 (Rahmat 2004). There were still 1,763,100 families living in poverty, with poverty line[1] less than Indonesian Rupiah (IDR) 102,912/month (Bandung City Statistical Agency and Planning Board of Bandung City 2003). Sundanese ethnic group represents the original culture in this region. Nevertheless, most of other ethnic groups in Indonesia also subsist in the Bandung Basin. Similar to other provinces in Indonesia, Islam represents the majority religion in the area, ahead of Christianity, Hinduism, Buddhism and other religions.

(2) Local Economic Condition and Major Economic Activities

In 2003, trade and industry excluding oil and petroleum contributed the largest portion of the Regional Gross Domestic Product (RGDP) based on current prices. Trade accounted for IDR 7,473,793 trillion and industry accounted for IDR 7,225,546 trillion, equal to 31.91% and 30.85% of the total RGDP respectively. Subsequently, transportation and communication accounted for 11.64%, and services were 10.79 % (Bandung City Statistical Agency 2003). In Bandung Regency, major earnings came from the processing industry (53.66%), followed by trade (17.41%) and agriculture (9.53%) (Bandung Regency Statistical Agency 2003). The same pattern can also be found in Cimahi City. In 2003, according to current prices, the industrial sector contributed around 68.08% of total the city's RGDP, followed by trade (15.19%), with construction ranking third followed by electric and water supply at around 4.28% (Cimahi City Statistical Agency 2003). Economic activity in Bandung Basin is concentrated in both the city and regency of Bandung, which is obvious from a comparison of the RGDP. The annual RGDP growth rate in the Bandung Basin reached 15.66%, whereas the highest growth rate occurred in Bandung City, at 19.56%. In 2003, the total RGDP for Bandung Metropolitan was IDR 56,262,565 trillion with the breakdown as follows: (1) Bandung City: IDR 23,420,125 trillion, with GDP per capita IDR 10,486,879, (2) Bandung Regency: IDR 23,833,127 triliion and GDP per capita achieved IDR 4,894,691, (3) Cimahi City: IDR 5,172,022 trillion and (4) Sumedang Regency: IDR 3,837,289 trillion (West Java Statistical Agency 2004).

1-4. Overview of Water Resources

(1) Precipitation

The mean annual rainfall in the Bandung Basin varies from 1,000 mm in mid-regions to the south-east of Bandung City, to more than 3,500 mm in the north and less than 3,000 mm in the south. The wet season extends from November to April. The yearly rainfall intensity ranges between 1,700 – 3,500 mm with a mean value of 2,195 mm/year[2]. The average temperature is 22.6°C, and evapotranspiration value is 1,060 mm/year.

(2) Water Availability

Surface Water Potency

The existing conditions of surface water in the Upper Citarum River Basin remained sufficient, indicating the different amounts under normal and minimum conditions. When the amount of surface water under normal conditions is 1.70857 billion m^3, the amount of surface water under minimum conditions will be 244.47 million m^3 (table 1).

1. This method is calculated by minimum expenses for food and non food requirement per capita per month
2. Based on data from Metrological and Geophysics Bureau 1955 - 2003

Table 1. Surface Water Balance in the Upper Citarum River Basin

Sub-Basin	Average Discharge (m^3/sec)			Volume (x 10^6 m^3/Year)		
	Normal	Dry	Minimum	Normal	Dry	Minimum
Cimahi	2.38	1.61	0.33	75.06	50.77	10.41
Cibeureum	2.26	1.53	0.32	71.27	48.25	10.09
Cikapundung	4.83	3.26	0.67	152.32	102.81	21.13
Cipamokolan	4.88	3.29	0.68	153.90	103.75	21.44
Cikeruh	4.17	2.81	0.58	131.51	88.62	18.29
Citarik	6.63	4.48	0.93	209.08	141.28	29.33
Citarum Hulu	7.99	5.39	1.11	251.97	169.98	35.00
Cisangkuy	12.04	8.12	1.68	379.69	256.07	52.98
Ciwidey	8.84	5.97	1.23	278.78	188.27	38.79
TOTAL	**56.02**	**39.46**	**11.53**	**1,708.57**	**1,155.80**	**244.47**

Source: Water Resource Agency of West Java 1996

Spring Water Potency and Groundwater Potency

Spring water is generally found in a conservation area that has a recharge area. The total discharge of spring water is less than 600 liters/second. The rate is not stable, but fluctuates according to the change in the seasons. Significant amounts of spring water were used as alternative water sources, particularly for rural areas. Most of the sources of spring water in the Bandung Basin are at an altitude that exceeds 750 m above sea level. The availability of spring water is 2,785 liters/second or 87,859,296 m^3/year (Gunawan 1995). Based on the potency, groundwater in the Bandung Basin is divided to three groundwater basin according to the Decree of Minister Energy and Mineral Resources No. 716.K/40/MEM/2003, namely, Lembang, Batujajar and Bandung-Soreang, classified as confined and unconfined (table 2).

Table 2. Groundwater Availability and Potency in Upper Citarum River Basin

Groundwater Basin			Rank of Investigate	Amount of Groundwater (x 10^6 m^3/year)	
NO	Name	Area (km^2)		Unconfined	Confined
1	Lembang	169	Known	164	16
2	Batujajar	89	Known	66	1
3	Bandung-Soreang	1.72	Inception	795	117

Source: Decree of Minister Energy and Mineral Resources No. 716.K/40/MEM/2003

Water Demand and Use

The water demand in the Upper Citarum River Basin was estimated using our analysis based on various data sources. In 1995, the projected water demand for the agricultural sector to irrigate field rice was 982.94 million m^3. It tended to decrease from time to time since more and more agricultural land are converted to built area. It is estimated that the demand from agriculture sector will be 0.27% per year. In 2005, the total demand for agriculture was 955.66 million m^3. Unlike the trend in agricultural demand, domestic demand tends to increase year on year due to the population pressure. Domestic demand in 1995 was 227.08 million m^3 and went up to almost 318 million m^3 in 2005. Demand from industry tends to increase with the upsurge of wet industry that consumes water in the processing. It is projected retrospectively that by 2000, the rate of water consumption in industry was 10% per year and subsequently went down to 8% per year. In 2005, water used by the industrial sector was 134 million m^3 (Water Resources Agency of West Java 1996). Surface water use is dominated by the agricultural sector. Every year, almost one million m^3 are allocated to irrigate rice fields. The water utilities obtain their water from raw surface water, groundwater and several spring wells. The volume of surface water taken was around 80 million m^3 in 2004, while the volume of groundwater was 7 million m^3 and spring water was almost 9 million m^3.

Water Supply System

The Bandung City and Regency Water Supply Enterprise (WSE) provides water for domestic use in the city and regency of Bandung. The percentage of the area currently served by Bandung City WSE achieved 52% with the number of direct connections at around 145,757 households. The Bandung Regency WSE serves only around 23% of the total population, with the number of direct connections being 34,381 households. Besides serving the residents of Bandung Regency, the Bandung Regency WSE also serves the resident of Cimahi City. The served area is around 20% with the number of direct connections being 24,752 households.

2. Groundwater Use and Associated Problems

2-1. The Pressure on Groundwater Use

The biggest consumers of groundwater in this area are the domestic and industrial sectors. From the data available, it is noted that over 50% of the water required for industrial processes in Bandung Metropolitan is supplied by groundwater. The lack of infrastructure provided by the water utilities increases the demand for groundwater. In addition, in several areas, the city and regency WSE also use groundwater for domestic water supply. The industrial sector seldom uses surface water. The reason is that more investment is required for the construction of raw water treatment plant than that for providing groundwater infrastructure. Another problem preventing the establishment of a water treatment plant is the lack of available land. In terms of operation and maintenance, it is more expensive to used treated surface water as the quality of groundwater is better than that of surface water. It is important to be noted that the types of industry that dominate in each cluster are wet industries, particularly textiles, so the water consumption is automatically expected to be higher. There is no specific institution that provides raw water to industry, so industry has no choice but to use groundwater in its activities. Another factor that increases reliance on groundwater is that groundwater is relatively inexpensive, compared to other water source including those supplied by the municipality or regency. Therefore, many residents prefer to use groundwater rather than other sources. Groundwater continues to be more reliable than other sources, also because its flow is not affected by peak times, unlike water supply from the city or regency WSE that often overload in peak hours. At present, there is no accurate data on how many m^3 are extracted by residents for domestic purposes in Bandung Metropolitan. Unlike the mechanism for the use of groundwater by industry, the use of groundwater for domestic purposes is not subject to the fifty-meter restriction for drilling down to extract water, nor is it subject to the restriction of 100 m^3 per month on the use of groundwater.

2-2. Trends in Groundwater Use

Groundwater abstraction has been thoroughly recorded by the Directorate of Environmental Geology since 1900. Groundwater abstraction from 1900 to the 1990s increased to the highest point in 1997. After that, due to economic crisis, many industry collapsed which resulted in decreasing in groundwater use. After the economy recovered, the trend of groundwater abstraction has resumed its increase. The trend of groundwater abstraction can be seen in figure 2.

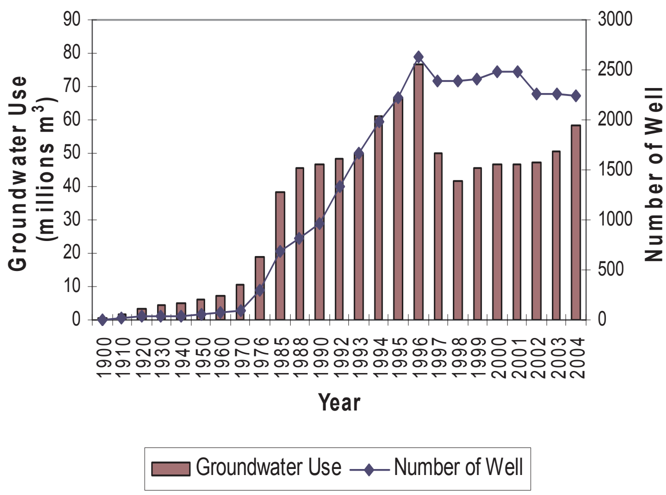


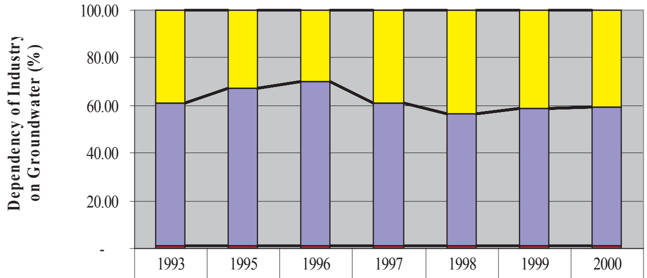
Figure 2. Numbers of Boreholes vs. Abstraction Period 1900 - 2004

Source: Based on monitoring data from Directorate of Environmental Geology (1900-2001) and the Mining Agency of West Java Province (2001-2004)

PART III

2-3. Groundwater Use by Industry

Nearly 50% of industries in Bandung Basin are textile industries, which include a water-intensive immersion process. Many of these factories are located in areas that have no infrastructure to supply water. Therefore, groundwater is a cheap and effective solution for factory operation. Groundwater use by the industrial sector in 1993 reached almost 59.55% of total water requirements, increasing to 66.34% in 1995 and slightly declined in 1996 to 59.60% from the total amount of water required. The economic crisis in Indonesia in 1997 also affected West Java Province and had a significant impact on groundwater abstraction as shown in figure 3. In 1999, groundwater use by industry declined to 57.20%, then increased to 57.84 % in 2000. Forecasts are that groundwater use will continue to increase until 2004, reaching almost 70% of the total water required by the industrial sector in the Bandung Basin. The reason for this is that, so far, the water supply infrastructure meets only two percent of total water requirements.



	1993	1995	1996	1997	1998	1999	2000
Surface Water	39.21	32.64	29.72	39.16	43.51	41.48	40.87
Rainfall	-	-	-	-	-	-	-
Spring Water	-	-	-	-	-	-	-
Ground Water	59.55	66.33	69.34	59.60	55.11	57.20	57.84
Water Work System	1.24	1.03	0.94	1.24	1.38	1.31	1.29

Year

Figure 3. Percentage Dependency on Groundwater Use in Industry Activities

Source: Based on various of data provided from Directorate of Environmental Geology, WSE and the Mining Agency of West Java 1995-2000

2-4. Groundwater Use by Domestic

Figure 4 indicates the level of groundwater abstraction from 1993 to 2000. According to the data recorded in 1993, groundwater use for domestic purposes was 104,218,377 m^3, and tended to increase through the period of 1997 - 1998. In 1995, the domestic use of groundwater reached 107,239,387 m^3 and declined to 95,088,048 m^3 in 1998. However, in 2000, the domestic use of groundwater increased to 114,328,950 m^3.

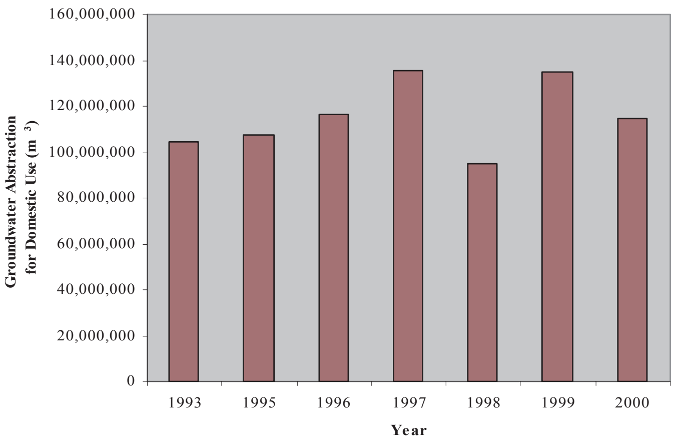


Figure 4. Projection of Groundwater Abstraction for Domestic Use 1993 - 2000[3]

Note: This projection is calculated by data of number of population that used water from well

3.The projection of groundwater abstraction for domestic use is counted based on number of population that have well and it is multiplied by water requirement is around 120 litters per capita

2-5. Associated Groundwater Problems

(1) Water Table Depletion

According to the data from monitoring wells during some periods, there has been a significant change in the water table in the Bandung Basin from positive artesian (flowing) to negative artesian (pumping). For example, positive artesis identified in the Dayeuhkolot-Bojongsoang area was +4.0 m above ground level in 1920, but in 1960 the water table had been depleted to +3.9 m above ground level. In the mid 1970s, the water table dropped to -2 m below ground level and had fallen to 40 to 80 m below ground level by 1990. The same phenomenon has occurred in one of area of Cimahi City. One monitoring well that has been observed since 1920 initially had positive artesis with a pressure of +19 m. In the mid 1950s, the pressure decreased and in the early 1980s the pressure reduced and reverted to a pumping phase with a pressure of -3 m below ground level. In 1985, the groundwater table reached -10 m below ground level, and in 1995, the water table was detected as - 40 m below ground level.

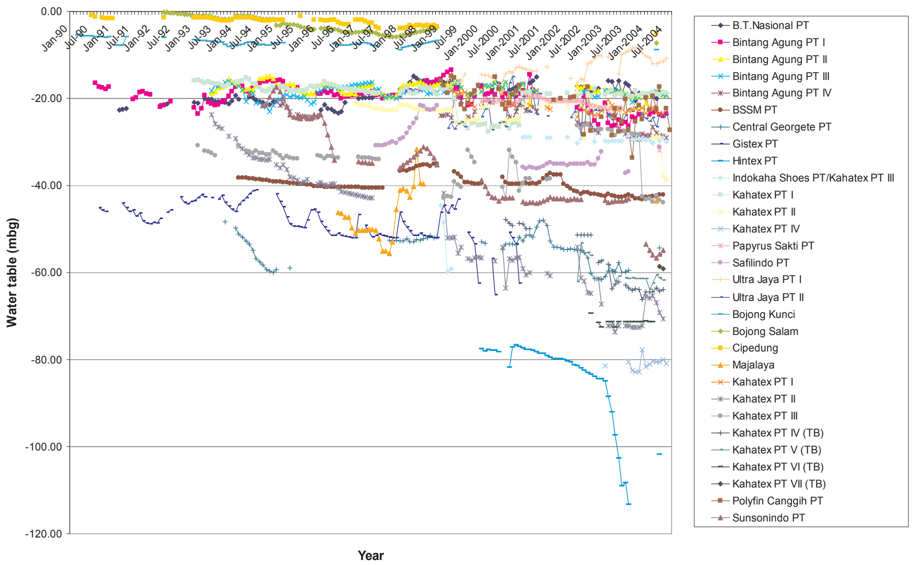


Figure 5. Water Table Depletion in Several Monitoring Well

Source: Data based on monitoring well from Directorate of Environmental Geology 1990-2004

The level of the groundwater is also monitored by automatic water table recorders (AWLRs) at 30 monitoring wells in the study area. The Geology Environmental Office identified the change in the level of the water table up to July 2004. The areas with the most severe depletion of the static groundwater level forming a cone of depression are Cijerah where the depletion exceeded 20 m during the period from 1997 to 2004, Cimanggung where depletion has exceeded 60 m over the past decade (1994 to 2004). In Rancaekek, depletion has also exceeded 60 m over the past decade according to data measured at the PT Kahatex deep well. In the Leuwigajah Industrial Estate, depletion reached 40 m over the period from 1994 to 2004. Moreover, groundwater depletion is also affecting WSE deep wells. There were 32 deep wells from which the WSE is extracting water and the volume declined from 550 liters/second in 1982-1983 to 115 liters/second in 2004.

From the empirical data above, the water table in mid-level aquifers ranges from 0.92 to 84.24 m and the water table in deep aquifers range from 62.83 to 85.76 m below ground level. Excessive consumption of groundwater especially in the dense industrial clusters has the manifestly negative effect of significant groundwater depletion. The results of the monitoring period from July 1995 to July 2004 concluded that the speed of groundwater depletion in mid-level aquifers is about 0.12 to 8.76 m/year and in deep aquifers is 1.44 to 12.48 m/year.

(2) The Symptom of Land Subsidence

Although many factors may have effect on land subsidence in Bandung Metropolitan, excessive groundwater abstraction for industry, trade and domestic use are deemed to be the main factors. Substantial land subsidence has occurred, particularly at deep aquifers. Replenishment of the groundwater takes many years. Land subsidence associated with shallow aquifers is not as severe as that associated with deep aquifers. The reason is that the groundwater in shallow aquifers is more readily replenished by surrounding surface water, particularly during the wet season. There has been substantial land subsidence since the 1980s associated with the increase in industrial activities and settlements. Subsidence was most severe in industrial areas such as Leuwigajah, Batujajar, around Mohamad Toha Street, Dayeuhkolot, Rancaekek-Cicalengka, Ujungberung, Cicaheum, and Kiaracondong. In settlements and residential areas, a decline was observed in the level of the groundwater, which was apparent from the difficulty experienced by residents in extracting water from their dug wells.

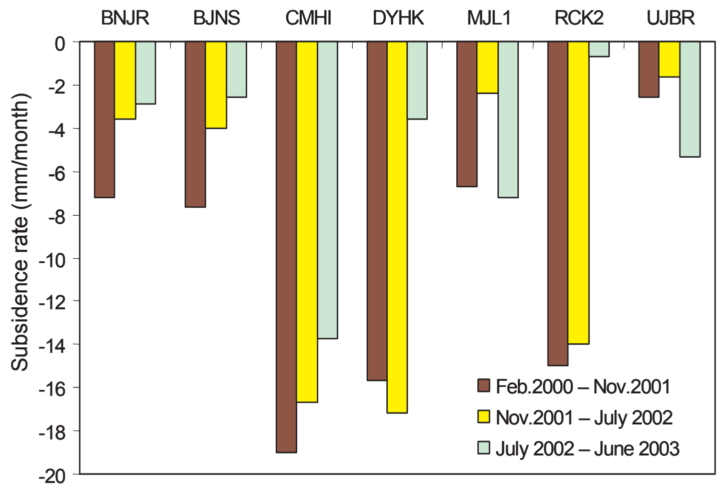


Figure 6. Average Temporary Land Subsidence in Various Areas
Source: Abidin et al., 2003

Land subsidence has been periodically measured using a Global Positioning System (GPS). According to the data from this system, land subsidence in several locations reached 20 mm per month or 24 cm per year, particularly in several areas that are critical in terms of groundwater zoning, such as Cimahi, Rancaekek and Dayeuhkolot (Abidin et al. 2003).

(3) Deterioration in Groundwater Quality

In 2004, groundwater quality was measured at a sample of 25 boreholes. Of the sample, 19 boreholes (76%) have most probable number (MPN) of total coliform exceeding the standard of 1000/100 ml, with the remaining 24% being below this level. Eighteen of the sample of 25 boreholes (72%) has most probable number (MPN) of fecal coliform exceeding the standard for class 1, namely 100/100 ml. These results indicate the need to treat the water obtained from these locations before domestic consumption. Many of the locations sampled were in densely populated residential areas while others were in the industrial area of the Bandung Basin. The result of laboratory tests on 50 samples from various location in the Bandung Basin in 2005 revealed that 78% of the samples did not meet the standard and 70% exceeded the fecal coliform standard. Only one location had an absence of coliform bacteria, which was thought to be due to the fact that the well was quite deep. In fact, 90% of all dug wells sampled were relatively close to septic tanks. (According to our standard, dug wells should be at least 10 m from the nearest septic tank). It is believed, therefore, that all the dug wells have been contaminated by domestic waste. Another reason for the high levels of coliform exceeding the standard is the poor state of sanitation around point at which the water is extracted.

3. Policy Responses and Future Challenges

Table 3 provides a brief explanation of the chronology of groundwater management in Bandung Metropolitan.

Table 3. Chronological of Groundwater Management in Bandung Metropolitan

Year	Policy	Level
1945	**Fundamental Act of 1945 (UUD 45)** Natural resources, including water resources are considered a public good that must be managed fairly, and used for the benefit of Indonesian people.	National
1970	**President Decree No. 64 of 1972 Regarding Groundwater administration** Governor has authority to issue a license for groundwater use	National
1974	**Act Number 11 Year 1974 on Watering** • Groundwater is a public good that has a social function and shall be used optimally for the wellbeing of the people. • Authorization for water management is divided into two bodies i.e. all water *except groundwater* becomes the responsibility of Minister of Watering, while groundwater is the responsibility of the Mining Department/ Minister of Mining.	National
1980	**Monitoring Research by Geology Environment Office (Under Minister of Mining and Energy)**	National
1982	**Central Government through Government Law on Water Arrangement 11 of 1982**	National
1982	**Governor Decree No 181/SK.1624-Bapp/82 of 1982** Land Use Planning for the Bandung Basin for the Relocation of Industry and Infrastructure for water utilities	Provincial
1990	**Plan of Determination of Zoning by Geology Environment Office (Under Minister of Mining and Energy)**	National
1994	**Minister of Mining and Energy Decree No. 02P/101/M.PE/1994** Recommendation for Zoning in the Bandung Basin	National
1995	**Directorate Environment Geology Decree 005.K/10/DDJG/1995** Technical Guidance for Groundwater Management	National
	Provincial Regulation No.9 of 1995 Regarding Groundwater Controlling and Surface Water	Provincial
	Local Regulation No. 43 of 1995 Regarding Permit for Groundwater Controlling	Local
1997	**Act Number 18/1997 on Local Tax and Retribution,** Tax on surface water and groundwater usage is classified as second state government tax	National
1998	**Bandung City Government Rule Number 3 Year 1998** Tax charged at the maximum rate of 20%.	Local
1999	**Act No. 22 of 1999** For Decentralization, groundwater management is the responsibility of the Local Government	National
2000	**Act Number 34 Year 2000 on Amendment of Indonesian Republic Act Number 18 Year 1997** Several mechanisms changed for collecting tax. Act 18/1997 stated that the Local Government has the authority to collect taxes for Groundwater Abstraction, whilst according to Act 34/2000 Article 2, the collection of such taxes forms part of Provincial Government Revenue.	National
	Minister of Mining and Energy Decree No. 1451.K/MEM/2000 Technical Guidance for Groundwater Potency Evaluation and Appendix 2 on Technical Guidance for Groundwater Planning and Usage	
2001	**In 2001, West Java Province Government issued Province Regulation Number 16/2001** Relates to Groundwater Management	Provincial
2002	To support provincial regulation number 16 of 2000, **West Java Governor Decree Number 23/2002** on the Guidance for the Implementation of Provincial Legislation Law Number 16/2000 was issued in 2002.	Provincial
	Regulation Number 8/2002 issued by Bandung City has similar substance to provincial regulation. Domestic use below 100 m^3 per month with a depth ranging from 40 to 60 m does not need a license for an abstraction well.	Local
2003	**West Java Governor Decree Number 29/2003** issued as basic for groundwater usage tax calculation. There are three main considerations: water is a natural resource, water should be conserved and the price of raw water	Provincial
2004	**Water Resources Act No. 7 of 2004**	National
	Cimahi Regulation Number 16 of 2004 on Groundwater Management	Local
	Act 32 of 2004 on Revised of Decentralization, The substance is to return the authority for groundwater from the local government to the provincial government.	National

PART III

3-1. Overview of the Policies

Basically there have been several regulations in the effort to improve groundwater management in Bandung Metropolitan since the 1980s. However, obstacles remain to implement the regulations issued by both by the provincial and local government. For instance, the idea of limiting the excessive use of groundwater through stopping new licenses and zoning for critical areas is also difficult to implement without further strategies to provide water source alternative. Table 4 explains the effectiveness of and deficiencies in the existing measures.

Table 4. List of Measures and the Effectiveness of Policies in Bandung Metropolitan

Measures	Date Implemented	Effectiveness	Deficiencies
Using of License	1974	N/A	Unregistered wells still exist particularly in industry
Zoning Area 1. Critical Area 2. Vulnerable Area 3. Safe Area	1994	N/A	Water table depletion is still happening in critical areas
Groundwater Usage Charge	1974	N/A	No charge for domestic use as water is a public resource
Abandonment of Groundwater Wells by WSE	1990	N/A	Groundwater sources are still used by WSE for certain areas
Plan for Industry Relocation	1990		High costs
Groundwater License Requirement Based on Technical Aspects: 1. Depth and Length of Strainer 2. Discharge of Pipe Diameter 3. Power of Pumping Equipment 4. Depth of Well 5. Pizzometer Pipe Diameter 6. Depth of Aquifer Extracted	1995	Effective	
Limiting Groundwater Abstraction	1995		Water table depletion continues.
Groundwater Charge	1995	Effective for industrial use but not effective for domestic use	No charge for domestic use
Metering	1995	80 %	Not all wells are metered.
Decentralization (Hand Over Groundwater Management Authority from Centre to Provincial and Local Government)	1999		
Stopping a New License for Certain Areas	2000		Water table depletion continues.
Land Use Regulation	2000		Uncoordinated land use planning between provincial and local level
Groundwater Tax Based on Natural, Conservation and Raw Water Price	2001	Effective for industrial use but not effective for domestic use	No charge for domestic use
Establish Monitoring Well			Water table depletion continues.
Introduction of Recycle and Reuse Technology	2000	Not effective	No incentive for industries that have complied with the initiative
Reporting of Groundwater Extraction		Effective for determining how much groundwater has been extracted for industrial use	
Introduce Recharge Wells for Both Domestic and Industrial Use Particularly in Conservation Areas	1995	N/A	Only 5% of people residing in the conservation area complied with this regulation.
Groundwater Data and Information System	2002		Not updated
Closing Unregistered Wells		Effective	

Note: This table was created based on the Stakeholders Meeting, Bandung Case, January 2006

3-2. Challenges to Improving Groundwater Management

The dependency of industry on groundwater is one of the constraints faced by groundwater management. This dependency is associated with the lack of infrastructure provided by WSE. According to the most recent data, the amount of clean water that WSE supplied to the industrial sector was only about 3.5 million m^3 in 2003, which is just 1% of the volume required by industry. This means that almost all water required by the industrial sector comes from groundwater.

Another factor influencing the scarcity of groundwater is the condition of groundwater recharge area. Groundwater recharge can be interpreted as the addition to the groundwater from an external area to the saturated water column. Generally, groundwater is replenished from rainfall, rivers and human intervention such as an artificial recharge well. One of the main factors influencing groundwater depletion is significant changes in the land cover from natural terrain to built areas. These changes can disturb the hydrological function in the upper Citarum watershed. The influences will get worse if the changes in land use occur in the recharge area. According to the analysis by Geology and Environment Directorate, 1996, concerning the recharge areas in the Bandung basin, there are 21 sites of recharge areas in the upstream of the Citarum watershed that are classified as the main recharge area accounting for 60,881.31 hectares or 26% of the total recharge area. In addition, the Chaffy recharge area accounts for 67, 911.89 hectares or 29%, and an additional recharge area accounts for 56,069.66 hectares or 24%. Despite this, there are also releases from charging areas equal to 38, 970.4 hectares (16.6%) (Directorate of Environmental Geology and Planning Board of West Java 1996). Generally, the recharge mechanism in a shallow aquifer in the Bandung Basin is a direct process, irrespective of whether it is a natural or human intervention, and it occurs either instantaneously or over the period of a week. The process of recharging mid-level aquifers and deep aquifers occurs directly or indirectly. Direct processes occur in the main recharge area and indirect processes occur in almost every watershed area. This condition is due to the isometric height from the deep groundwater located under shallow groundwater. It means that the shallow aquifer is first recharged, then the water continues to the mid-level and deep aquifer through leakage.

The groundwater management problem in the Bandung Basin has many dimensions, one of which is providing alternative source of water for industrial use. Looking at the groundwater control mechanism in the Bandung Basin, licensing is still considered the main tool for controlling groundwater abstraction. This mechanism would not work with the bare minimum awareness of the stakeholders about the importance of groundwater conservation and weak law enforcement and monitoring. The fact is that in the Bandung Basin, many unregistered deep wells have been found. There are no incentives such as tax compensation for industries that recycle water. The result is that many industries are not interested in water conservation, making it extremely difficult to control groundwater extraction in the Bandung Basin.

The failure of water utilities to supply raw water and to extend the coverage area has also become a trigger for the groundwater problem. The coverage as a percentage by WSE is 37.75% (50% for Bandung City, 23% for Bandung Regency, 7% for Sumedang Regency and 20% for Cimahi City). The raw water for WSE comes mostly from surface water with the biggest service provided for domestic use. Industry still depends on groundwater, and since industries are self-regulating, groundwater control becomes difficult.

The future challenge for groundwater management is to alter the mechanism of water provision that currently applies. Tax based on a calculation of water value provision provided is divided into three components. The mechanism provided a price below that which applied to WSE. Simulated calculations concerning the costliest component indicated that the price that must be paid according to the current mechanism of water provision is much cheaper than the tariff released by WSE. Under this mechanism, the price for 1 to 500 m^3 is IDR 1,038 per m^3, the price for 500 to 1,500 m^3 is IDR 1,668 per m^3, the price for 1,500 to 3,000 m^3 is IDR 2,298 per m^3, the price for 3,000 to 5,000 m^3 is IDR 3,138 per m^3. In comparison the tariff for WSE is IDR 1,750 to 9,600 per m^3 for usage by the industrial sector.

3-3. Issues from the Stakeholders' Meeting

The stakeholders' meeting conducted on 12 January 2006 discussed several issues present and future due to barriers and deficiencies in groundwater management in Bandung Metropolitan. The biggest challenge in handling the problem is how to comply with the enacted laws and regulations. There are policies and regulations that have been issued to preserve the groundwater, yet they are difficult to implement. As we discussed prior to the meeting, the failure to make optimum use of surface water is another reason why the stress on groundwater is difficult to manage. To synchronize and clarify the issues identified in this study, a stakeholders' meeting was convened with invitations extended to related stakeholders at all levels, particularly at the provincial and local level. The reason for inviting these parties is because, according to recent regulations on decentralization, the management of water resources has been hand over to local government. There are 22 related groundwater issues which were agreed on by the participants in the stakeholder meeting. There is no specific institution handling this subject that also attended the meeting. Table 5 indicates the results of issues identified at the stakeholder meeting.

Table 5. Issues Identified for Groundwater Management in Bandung Metropolitan

Issues and Concerns
Excessive groundwater abstraction
Water table depletion
Land subsidence Symptom in Certain Area
Lack of alternative water sources
Lack of water infrastructure for domestic use
Water loss of WSE
Monitoring of actual groundwater use
Permits from the building development office does not consider water resource limitations
Groundwater abstraction exceeding groundwater replenishment
Changes in land coverage from recharge water area to built-up area
Lack of public awareness of the environmental function of groundwater
Poor controlling of groundwater usage
Lack of law enforcement
No agency specifically dealing with industrial water supply
Price of groundwater cheaper than WSE price
Unregistered wells particularly for industrial use
Lack of database system
Deterioration of groundwater particularly in shallow aquifers (domestic use)
Licensing does not consider water source availability
Improper land use planning
Limited natural resources
Differing perceptions concerning groundwater sources between stakeholders

Note: This table was created based on the Stakeholders Meeting, Bandung Case, January 2006

4. Proposed Policy

4-1. Recommendations

The stakeholders' meeting in January 2005 in Bandung identified issues and reviewed regulations concerning groundwater management, including their effectiveness and barriers. The meeting also tried to propose policy options on how to improve Bandung's groundwater management. The agency responsible for implementing the proposed policies also proposed in the meeting. One of the outcomes is to establish regulations for water resources (surface and groundwater), which will be backed up by legislation. The result of this subject can be seen in this table 6.

Table 6. Proposed Policies for the Management of Groundwater Resources

Proposed Major Policies	Responsible Agency/Stakeholder
Amendment of groundwater sources regulations (the material will integrate groundwater and surface water)	Legislation, Mining Agency, EPA, Law Bureau
Substitute groundwater for surface water	Planning board, EPA, Industrial Office, Spatial Plan
Development of artificial dams	Public works office
Extend the pipeline for WSE	WSE
Relocate industry	Planning board, EPA, Industrial office, spatial plan
Plan to stop groundwater pumping in certain areas	Mining Agency
Recycling and reuse program	EPA, Mining office & Industrial Office
Promotion of clean technology	Industrial office and EPA
Artificial recharge wells	Mining Agency, EPA
Integration and synchronization between agencies which provide licenses and WSE	
Integrated planning across boundaries	
Provision of incentives for the recycling and reuse of water	Mining office, Industrial office & EPA
Private sector involvement in the collection of groundwater charges	Mining office
Improve the system for monitoring of groundwater wells	Mining office
Groundwater quality monitoring system including for shallow aquifers	Mining Agency, EPA
Land acquisition or land protection in potential water catchment areas	Spatial plan office & Procurement Bureau
Review of conservation area regulation and enforcement	Law Bureau, Mining Office, EPA, Police Office
Rainwater harvesting	Mining office, industrial office, EPA. Public
Incentives for water conservation	EPA
Industrial water supply system	Public Works Office
Public awareness and education programs	Attached in related sectors
Increased groundwater charges	Mining Office & Industrial Office
Limiting groundwater extraction	City Plan Office, Planning Board, Mining Office,
Enhancing/promoting aquifer replenishment (natural and artificial)	University, Mining Office, EPA

Note: This table was created based on the Stakeholders Meeting, Bandung Case, January 2006

(1) Legal Aspect

From the policy aspect, the enactment of Law Number 22/1999 and Revision Number 32/2004 on Local Government (Decentralization) has implications for the groundwater management policy. Under this law, the authority for groundwater management has been devolved from the Directorate of Geology and the Environment to the local government. Decentralization seems to be another trigger for the poor management of groundwater as it is considered as trans-boundary natural resources. Besides, an amendment on groundwater regulation is particularly necessary concerning how the regulation can accommodate both technical and economic requirements. It is necessary to integrate the groundwater and surface water and establish incentives and disincentives mechanism in the

PART III

official regulations, so that industry will engage in clean technology, implement reuse and recycling programs and perform rainfall harvesting subsequently. The substances of these outcomes will be brought before parliament or legislators as draft legislation about the management of water resources at both the provincial and local levels. Consistency in enforcing the existing or amended policies to be issued and the imposition of penalties, such as the cancellation of industrial licenses for exceeding the limits for groundwater abstraction, has the unanimous agreement of all stakeholders.

(2) Economic Measures

Several recommended policies were proposed at the stakeholders' meeting. These included incentives and disincentives for industrial use, increased groundwater levies or taxes for industrial use so that the water becomes more expensive than the charge for WSE.

(3) Technical Measures

In perspective of groundwater utilization and management, a review needs to be done with the aim of maintaining and recovering the groundwater level, so that the capacity of aquifers can be sustained. Policy alternatives for changing the water source from groundwater to surface water, particularly for industrial use, need to be considered. Another alternative is to relocate industrial cluster to other areas designated as industrial estates. In this case, however, relocating industry to another location where there is abundant surface water will also require development of the infrastructure. This option has significant weaknesses in implementation, i.e. a high level of investment as well as the politic and social costs that the government has to bear.

Appropriate available technology for recycling is another alternative that can be implemented by industry to meets its water requirements. Consistency and support from the government in the implementation is the key to the success of this programme.

(4) Informative Measures

Through public awareness and education such as the Save Water Movement, the government at each level should promote water saving and disseminate the problems associated with both groundwater and surface water.

(5) Support Measures

Several recommendations have also been proposed to cope with groundwater problems: Establish a proper groundwater monitoring system to deal with quantity and quality, land acquisition for conservation area thereby enhancing both natural and artificial recharge aquifers, and establish trans-boundary integrated planning.

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Groundwater Resource Management in Sri Lanka

Gemunu Herath and Uditha R. Ratnayake

1. Background of the Study Area

This study investigation mainly focuses on groundwater management in two urban centers in Sri Lanka and briefly discusses the groundwater use in agriculture and the impacts caused to the coastal groundwater reserve from the tsunami. The two urban centers selected are the urban and suburban areas of the capital city, Colombo, in the western-coastal region and Kandy, which is located in the central hills of Sri Lanka (figure 1). Groundwater use in agriculture is discussed through the agro-wells (wells that are used for agricultural purposes) in the north-western regions, while the impact of the tsunami is through the coastal groundwater resources.

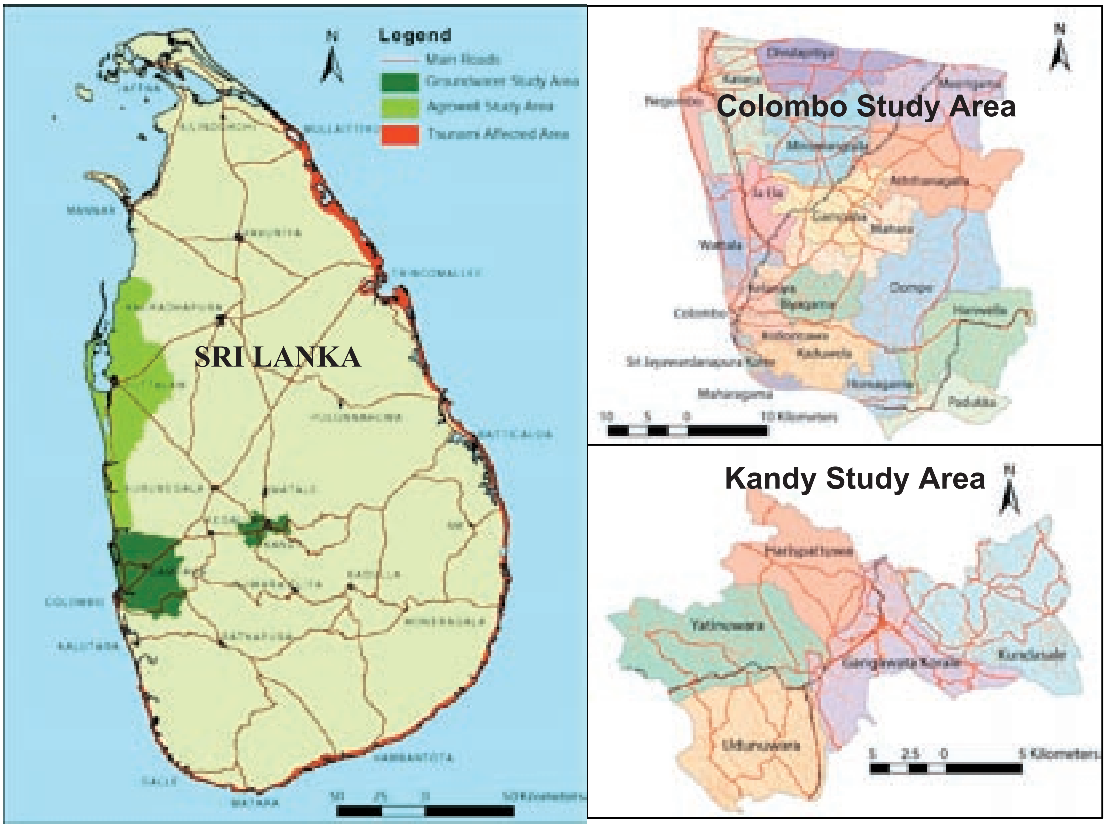

Figure 1. Case Study Areas

1-1. Administrative Structure

Sri Lanka has nine provinces, each with its own local government. The provinces are further subdivided into districts with the total number of districts in the country being twenty-four. These are again subdivided into divisional secretariat areas responsible for civil affairs, which in turn are divided into the smallest administrative divisions, called "*Grama Niladari Divisions,*" at the village level. The Colombo study area contains twenty-one divisional secretariat divisions while the Kandy study area is restricted to five divisional secretariat divisions.

1-2. Topography, Geology and Climate

Sri Lanka has a central mountainous region rising up to 2500 meters above mean sea level, with the highest elevations covered by virgin forests and grasslands and surrounding plains, which rise to about 50 to 100 meters above sea level. The plains that are largely used for agriculture, homesteads, still have virgin scrubland where the population distribution is less. Colombo and its study area is located in the coastal plains in the western region of the country. The terrain in Colombo is of gently undulating plains with highly dense drainage paths. The terrain around Kandy (500 to 700 m above sea level) does not contain steep, plunging slopes. The topography in this plateau consists of undulating plains with hillocks formed by drainage paths separating them.

Sri Lanka is divided mainly into three different climatic zones based on the amount and pattern of the rainfall received. The zones are referred to as wet zone, intermediate zone and dry zone. Rainfall in Sri Lanka mainly occurs during the Southwest and Northeast monsoons and during the inter-monsoons. Both the selected urban areas are located in the wet zone, which receive an average annual rainfall of about 2500 mm. However with the recent climatic changes, the average rainfall iso-lines from 1911 to 1940 compared with the average rainfall iso-lines from 1961 to 1990 show that the rainfall has significantly reduced all over the country and specially around Kandy (Ratnayake and Herath 2005). It is revealed that the lengths of the dry periods have increased all over the country and the lengths of wet periods have decreased. This climatic change has directly affected the groundwater by reducing the recharge time corresponding to the lengths of the wet spells and increasing the exploitation with increased use during dry spells.

The major geological feature of Kandy city and the surrounding area is the band of marble one kilometer thick. This band can be classified as coarse crystalline mainly made up of calcite. Calcsilicate gneiss intruded as bands within the host marble including scapolite and spinel as additional minerals. Collectively these two rock types give rise to red-brown overburdened latosolic soil that on average ranges in thickness from one to three meters. The geology of Colombo is representative of the western coast of Sri Lanka and they have existed for much of the Quaternary era. Bore holes drilled in the central city show that the area once formed the estuary of the *Kelani* River and the *Kalu Ganga* River, the two main rivers that drain into the sea on the western coast. A few kilometers upstream in the inland valleys, there is a high-level gravel formation consisting of quartz pebbles embedded in a matrix of laterite separated with pebble free layers of laterite. The floodplains consist mainly of alluvial deposits. The floodplains of the Kelani River provide thick alluvial profiles for unconfined aquifers. Productive overburden aquifers also exist along the banks of tributaries.

1-3. Socio Economic Conditions

Regionally, Colombo and its suburbs accommodate the densest population in Sri Lanka. As of 2001, the total population living in Colombo study area was 4.3 million. The total population in 2001 of the Kandy study area was 1.27 million. The average population growth rates during the past 20 years in the Colombo and Kandy regions are 0.56% and 0.82% respectively. Both these averages are lower that the current country average of 1.3%. The GDP of the country at US$879 in 2000 has increased to US$1160 in 2005 (estimated).

1-4. Land Use

The total land coverage in the Colombo and Kandy case study areas are 1575.6 km^2 and 322 km^2 respectively.

Table 1. Land-Use Change in Colombo and Kandy

Land-Use Type (km^2)	Colombo			Kandy		
	1987	1998	% change	1988	1996	% change
Agricultural land	572.5	799.1	39.6	109.1	104.4	-4.3
Built-up land	12.7	131.2	933.1	5.6	8.3	48.2
Forests	36.4	30.5	-16.2	22.1	46.5	110.4
Domestic gardens	848.1	560.9	-33.9	175.6	149.9	-14.6
Water bodies	53	21.5	-59.4	9.6	10.4	8.3
Mangroves and marshes	52.9	32.4	-38.8	-	-	-

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The land use changes during the recent past in these regions are tabulated in table 1.

According to this data, the main land use change seen in both the study areas is the rapid increase in built-up areas, where in Colombo, the increase has by a factor of nine within the eleven years from 1987 to 1998. The main reduction has been in domestic gardens, water bodies and marshes (a typical domestic garden in Sri Lanka mainly consists of mixed vegetation that surrounds the house). Migration and the abandoning of agriculture for perennial crops are said to be the main reasons for the reduction in domestic gardens. However, the most significant change in relation to this study is in the reduction of cropping efficiency of paddies that cover nearly 20% of the area. This change is happening in both study areas and is not reflected in the land use maps. The cropping efficiency in the late seventies was nearly 200% with two cultivation seasons, while in the last decade, this dropped to an average of 140%. This has substantially restricted the amount of water in the paddy fields, thereby reducing the sub-surface flow and recharge, which influences the groundwater resources in the regions.

1-5. Water Resources

According to the *EarthTrends* country profile on Sri Lanka (2003), the total renewable water resources available in the freshwater ecosystems in Sri Lanka is estimated at 49 cubic kilometers of surface water, 8 cubic kilometers of groundwater and a further 7 cubic kilometers in overlapping water. The wet zone, which receives more than 1900 mm of rainfall, generates 49% of the total runoff for the entire country. Due to the high level of rainfall in the wet zone, the overburden is kept moist, which allows considerable subsurface flow through the macro pores. This subsurface flow is tapped using wells, which provide the water source for the majority in this zone. The Colombo study area is the lower part of the Kelani and Attangalu River catchments. The Colombo area receives an average annual rainfall of 2376 mm (40-year average) while the Kandy study area, which is located in the middle parts of the Mahaweli River catchment receives an average of 1841 mm (60-year average).

2. Groundwater Resources and Their Use

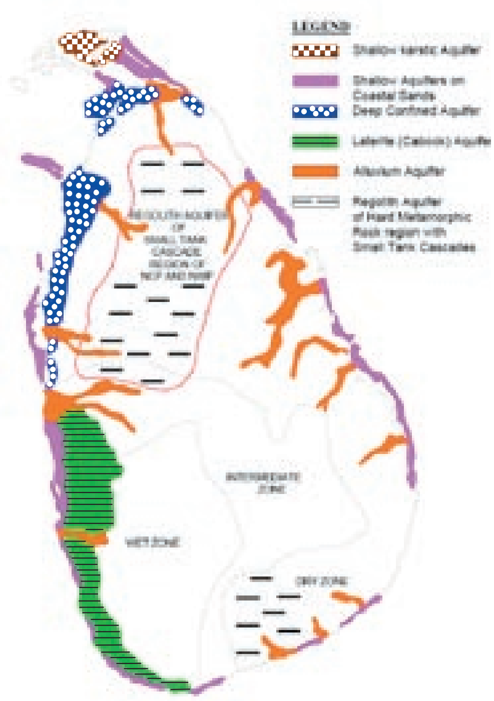

Figure 2. Distribution of the Major Aquifer Types in Sri Lanka

There are six main type of groundwater aquifers demarcated and identified in Sri Lanka They are shallow karstic aquifers, coastal sand aquifers, deep confined aquifers, lateritic (cabook) aquifers, alluvial aquifers and shallow regolith aquifers in the hard rock region. Figure 2 shows the distribution of these aquifers. In addition to these major aquifers, a large number of small groundwater pockets can be found throughout the country. These aquifers occur in either isolated patches of soil cover over the bedrock or in the fracture and weathered zones of the underlying metamorphic bedrock formation.

2-1. Groundwater Hydrogeology

Colombo: The basin hydrology indicates that there is a fair amount of groundwater potential both in the alluvial aquifers and bedrock. The prominent aquifer bedrock types in the basin are quartzite and a few crystalline limestone (marble) bands. The secondary porosity of these formations provides excellent conditions for deep aquifers. The alluvial sand/gravel aquifers in the basin are recharged by rainfall seepage from the rivers. High-potential porous residual laterites also contribute to groundwater supplies. During droughts, river water and springs recharge most alluvial aquifers in the basin.

Kandy: Groundwater in Kandy exists mostly in the form of semi-confined aquifers in the first 100 m of the bedrock. Groundwater storage exits as small pockets of underground reservoirs or as fissure groundwater. The available amount of water in these aquifers is not very well known and is limited as the recharging of these aquifers is very slow. In addition, there exists high-yield groundwater resources along the alluvial flood plains of the Mahaweli River and are mostly recharged by the river water.

2-2. Sustainable Aquifer Yields

Although there have been no detailed studies done, the projected sustainable yields from the different types of aquifers available in the regions are estimated as indicated in table 2 below.

Table 2. Rough Estimations for Sustainable Yields

Aquifer Type	Estimated yields (m^3 per sq km/day)
Gravel/Pebble	2500
Vesicular laterite	2000
Karstic Crystalline Limestone	1800
Quartzites	2000
Fractured bedrock	1500
Clayish sands	1000

2-3. Groundwater Usage Practices

(1) Domestic

The demand for groundwater in Sri Lanka is steadily increasing. The demand is particularly strong for urban and rural water supplies for use in irrigated agriculture and the industrial sector. This rapid increase in demand is exerting considerable pressure on the available groundwater resources. According to the WHO/UNICEF report on "Joint Monitoring Program for Water Supply and Sanitation-2000", only 76.1% of urban population was supplied with a piped water supply compared to 11.4% in rural areas, while the urban and rural population using underground well-water was estimated to be 22.4% and 71.8% respectively. (The urban and rural populations in 1999 were 5.86 and 13.05 million respectively.) In addition, the recent use of groundwater is increasing mainly because of the high cost of piped water and because of restrictions on supply. Under these conditions, therefore, many industrial and commercial users and some individual domestic users around the country who are already supplied with piped water also have a supplementary groundwater supply to reduce costs and to ensure a margin of safety in their supply. Of these, most industries today rely heavily on deep wells because groundwater is cheap, safe, of good quality, and is able to be autonomously managed. Presently, there are about 30,000 deep groundwater wells registered with the Water Resources Board throughout the country. Also there are 93 urban and rural piped water supply schemes operating across the country that rely entirely on groundwater for their supply, accounting for 31% of the total (Panabokke and Perera 2005). The total amount of annual groundwater abstraction from these 93 schemes exceeds 16 million cubic meters. In the regions of the case study, the total number of recorded deep groundwater abstraction wells in the Colombo, Gampaha and Kandy districts are 342, 890 and 1754, respectively. In addition, the approximate amount of groundwater used in piped water supply schemes in the Gampaha and Kandy districts are 5859 m^3/d (10%) and 13,233 m^3/d (30%) respectively (Panabokke and Perera 2005). There are no groundwater piped water schemes operating in the Colombo district. According to the Department of Statistics, the piped water coverage and population using groundwater in 2001 in Colombo was 64% and 33.5%. In Gampaha it was 22.2% and 73.4% and in Kandy it was 40% and 50%. Individual domestic groundwater consumers in the Colombo and Kandy study areas are estimated to be using approximately 157 and 24 million cubic meters a year. (In the case of individual groundwater abstractions, as there is no system of recording the groundwater use, only estimations can be made.) Here it should be noted that the above individual domestic groundwater usage estimations exclude domestic usage having piped water supply and use groundwater as their supplementary water source. As the percentage of domestic usage having a piped water supply and using groundwater as a supplementary source, especially in peri-urban areas, is believed to be high and increasing, the above estimations may be substantially low.

(2) Agriculture

As a result of the many subsidy programs intended to diversify agricultural activities and because of the changes in the rainfall patterns, groundwater use, both as a supplementary source and as a means of cultivating short-term crops during the dry season, has recently become very popular among many farmers in the dry zone of Sri Lanka. For these abstraction, farmers most commonly use either tube-wells (boreholes) or dug wells. Dug wells are fairly large in diameter (4 to 6.5 m), are usually manually excavated, are shallow (4.5 to 12 m) and may or may not be equipped with a motorized pump. These wells, when used for agricultural purposes, are commonly known as agro-wells in the country. With the Government and NGO-assisted subsidy schemes, the growth in agro-wells is progressing at a rapid pace. At the end of 2000, the total number of agro-wells stood at 50,456, while in 1985, there were only 500 (Kikuchi et. al. 2003). This rapid, haphazard expansion of agro-wells without appropriate assessment of the factors, such as the hydrogeological environment is expected to create many problems. As farmers are used to abstrating groundwater at rates typically ranging between 27 m^3/hr and 45 m^3/hr (Premaratne and Liyanapatabendi 1994), these high pumping rates are believed to be the most likely potential cause of conflicts because of overexploitation of the groundwater resources, either on a local or regional scale.

3. Problems Associated with Groundwater

In Sri Lanka, over the past 30 to 50 years, there have been two state agencies involved in groundwater studies, investigations and development of the resource. They are the Water Resources Board (WRB) and the National Water Supply and Drainage Board (NWS&DB). In addition, a few private drilling companies and donor funded projects have also been engaged in the investigation and development of the resource. In terms of monitoring and data collection, these organizations collect data primarily for their own use, although some is shared with other agencies and some is released to the public. However, this collected data is limited only to deep wells constructed by the organizations. In most cases, the information is restricted to the drill log, the initial water levels and the initial water quality. There is no data available on wells constructed by other private drilling companies, NGOs or by other international organizations. Also, there is no groundwater-related monitoring whatsoever in Sri Lanka and there has been no effort to demarcate recharge areas either. Therefore, the effects of developments taking place in recharge areas are largely unknown.

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3-1. Issues in the Main Study Areas

The history of well construction in Sri Lanka is indicative of the success rates. NWS&DB is responsible for the rural and urban water supply for domestic use and is currently the largest organization that develops groundwater in the country. According to the well construction unit of NWS&DB, production wells that yield less than 20 liters per minute and the hand-operated tube wells that yield less than 4 liters per minute are classified as failures. According to this classification, the success rate of wells during the construction stage is currently about 80%. Some wells go dry in short time while others have little reduction in yield and continue at a lesser yield. Usually, after about five to eight years, a well will achieve a steady state. If a well fails to continue to function at the rates mentioned above, it will be classified as a failed well. Usually the success rate achieved at this stage is about 65%. The rate is slightly higher for dry-zone wells maintained by the community, which stay at about 70%. The lower success rate achieve by wells maintained by the local government is attributed to poor maintenance and excessive groundwater abstraction.

The WRB currently has a fair amount of data and experience related to groundwater exploitation. Personal communication has revealed that the reasons for the exact failure modes are not commonly known because one would require a borehole camera to investigate, and this facility is not available in the country. Clogging is one of the major reasons suspected when water in the fracture zone is abstracted. Collapsing sidewalls is another reason for failures, especially in other types of aquifers. In a few cases, the wells recovered after frequent flushing. Occasionally, the fracture zone has a very low recharge rate or the exposure to the recharge boundary may have a very small area. Therefore, at the beginning the well will yield acceptable rates due to the available storage. However, the yield will later drop because of the low rate of recharge. A siphon action within the fracture zone is also a possible cause, and once the water level drops due to pumping, thereby causing the siphon to fail, the yield will drop.

Though there are various opinions concerning the country's groundwater issues, the lack of data and the wide range of abstraction across a range of aquifer environments make the problem studying the aquifers very complicated. Therefore, the quantity and quality-related issues experienced in the study areas are discussed in a more general form.

Quantity-related issues: Most of the quantity problems experienced in the study areas occur either in the coastal aquifers, vesicular laterite aquifers or in semi-confined rock aquifers. Of these, the major aquifer found is hard rock type and current problems associated with these aquifers are very much localized. In addition, there is a significant amount of groundwater abstracted using the alluvial aquifers in the river alluvial deposits. Most of these abstractions are very productive and are used in a wide range of applications without any problems.

- In the coastal regions of Colombo, over exploitation is seen as a major threat to the sustainable use of its coastal sand aquifers. These thin, freshwater lens aquifers that float on saline water is often contaminated with saline water due to excessive abstraction, especially during prolonged droughts.
- In the regions of vesicular laterite aquifers, as some of the aquifers are highly productive, and in certain cases they are even used for medium-scale piped water supply schemes. Excessive abstraction that mostly occurs in the laterites located away from the flood plain results in the lowering of the water table. It is also observed that when these aquifers are used excessively, the aquifers themselves are subjected to localized groundwater table depletions that affect the groundwater wells in the surrounding area.
- The other type of groundwater exists as semi-confined rock aquifers. These aquifers are used in high-volume applications, such as industrial activities, and water-supply schemes. According to the NWS&DB, a fair number of these deep hard-rock abstraction wells have experienced either a rapid lowering of the water level or decreased yields or both. Since there is no continuous monitoring available, the only information available is the initial drill log and initial water level and test pump data. In some cases even this data is missing. The usual practice adopted by the authorities where there is a failure is to drill another new bore in the vicinity, and in some cases, only a few meters away from the existing facility. This has been possible since the groundwater resources in hard rock formations are highly variable even in very close proximity. Personal communication with some of the officials involved in groundwater abstraction suggest that a poor understating of the resource and poor preliminary investigations, inadequate monitoring and poor maintenance are the main causes for these failures.

Personal communication has revealed that there are a number of groundwater schemes in the study region, especially in Kandy, that have been abandoned due to groundwater depletion. Most of the schemes that were initiated in early eighties have failed in the region and, at present, the water supply is restricted to few hours a day on a few days per week. In Kandy region unlike in Colombo, the success of drilling new bores in the vicinity as a remedial measure was limited and in most cases, it was necessary to extract the water from remote locations, making the supply very expensive. Consequently, at present, a massive surface water facility to replace the groundwater schemes is under construction.

Quality-related issues: Table 3 below summarizes the general groundwater quality in the Colombo region according to some selected parameters based on measurements performed during the drilling of groundwater wells.

Table 3. GroundWater Quality in Colombo

Parameter	EC (μC/cm)	Chlorides (mg/l)	pH	T-Iron (mg/l)	Free NH_4 (mg/l)	Nitrate (mg/l)	Ps (mg/l)	Sulphate (mg/l)
Max.	1170	800	8	13	2	4	0.16	208
Min.	77	12	7	0	0	0	0	0

According to the data, groundwater quality in the region is fairly good, except for the high iron content in some of the locations. However, an investigation by Gunawardhana et. al., 2002 found that many in western Colombo have abandoned their drinking wells mainly due to problems with odor and taste. It also says that most of the industries in this area tend to discharge untreated or partially treated effluent into nearby drains, polluting the groundwater. Their study results have revealed that the groundwater in the area has higher Fe, Mn, Ag, Ni and Al concentrations. The summarized average and maximum concentration of heavy metals in well waters detected in this study is tabulated in table 4 below.

Table 4. Concentrations of Heavy Metal in the Groundwater in Western Colombo

Metal	Fe	Mn	Ag	Ni	Al	Cr	Cu	Pb	Cd	Co
Max. (mg/l)	9.27	0.92	0.58	0.21	5.62	0.13	0.03	0.04	0.00	0.02
Ave. (mg/l)	1.1	0.09	0.05	0.1	0.37	0.03	0.01	0.01	0.00	0.01

As in Colombo, there is almost no continuous monitoring of water quality in Kandy too. However, there are many bore-hole wells constructed in the suburban areas in Kandy. Based on the quality measurements taken in these locations during the test pumping, table 5 below summarizes the groundwater quality in the suburbs. According to this data, the hardness, iron and nitrite is of concern in some locations in southern, western and eastern regions. Hardness as high as 1125 mg/l has been recorded in these areas, with the total iron at 18 mg/l, nitrites at 128 mg/l and sulphates at 500 mg/l. The groundwater quality in the northern areas is very good quality.

In addition to these initial water quality measurements, there have been a few quality measurements taken over the last few years, although they have not been tested at regular intervals or at regular locations. Most of these quality tests are generally made on request and for some of the bore-holes used for community piped water supply schemes. This monitoring shows that the main quality concern in the shallow groundwater is contamination due to coliform.

Table 5. Groundwater Quality in Kandy's Suburbs (maximum observed values)

Parameter	EC (Mhos/cm)	pH	T-Iron (mg/l)	Sulphate (mg/l)	Hardness (mg/l)	Nitrite (mg/l)	Mn (mg/l)	F (mg/l)	P (mg/l)
East	2190	4.6 – 7.9	15.2	500	1096	128	1.5	0.9	-
North	790	5.8-7.5	4.8	50	197	3.5	0.5	0.65	0.2
South	705	5.6-8.5	18	0.5	1125	48	4.4	-	-

3-2. Issues Associated with Agricultural Usage

The aim of providing financial support for the agro-well program was to assist farmers to cultivate crops near their homesteads and to provide water to highland areas where cultivation depends on rainwater. However, it is now clear that farmers establish agro-wells to support paddy cultivation in areas where it is felt that gravity irrigation from the tanks needs to be supplemented. It is estimated that by the end of 2000, the total number of agro-wells will be 50,456 of which 40,746 will be in the northwest region alone. A Master Plan Study done by the NWS&DB shows that, in highland areas, for each acre irrigated (equivalent to 0.404 ha) there has to be 34 acres of recharge for there to be sustainability. For low-lying areas, this figure is 17 acres per acre. According to the IWMI study (Kikuchi et. al. 2003), the density of dug wells is as high as 27 per 100 ha (equivalent to 3.7 ha or 9.1 acres per well). A density of twenty-two dug wells per 100 ha has been observed in the study region (equivalent to 3.0 ha or 7.4 acres per well).

However, so far this program has experienced only a few cases where there have been adverse effects, especially due to the haphazard diffusion of the wells. There were no cases where wells have been abandoned, nor have there been any reports of the over depletion of groundwater or an adverse impact on water quality due to the pumping of water from agro-wells. The only exception was in one scheme where farmers in the lower reaches complained that heavy water-pumping from unlined dug wells in the upper reaches had an adverse impact on the groundwater as well as on the surface water in the lower reaches. There are many abandoned wells, particularly lined dug wells, in the paddy areas and highlands in these irrigation schemes. However, the major reasons for abandoning the wells have been the poor quality of the groundwater in the area and low profitability, not the depletion of groundwater due to pumping (Kikuchi et al. 2003). This low incidence rate may be due to the fact that the agro-wells in Sri Lanka have a relatively short history of about only a decade. Therefore, a proper policy framework should be in place to ensure sustainability of the program in the longer term.

3-3. Effects of the Tsunami on Coastal Groundwater

Sri Lanka has a coastline of approximately 1660 kilometers. This coastal zone is very diverse, and contains lagoons and estuaries, fringing and offshore reefs, mangrove swamps, sea-grass beds, salt marshes, beaches, sandy spits, rocky shores and dune systems. Shallow groundwater wells have traditionally provided the main domestic water source for the settlements throughout the entire coastal areas. The Asian tsunami on December 26, 2004, hit the Sri Lankan coastline with various degrees of impact, but the eastern, northern and southern coastlines in particular were devastated (ADB, 2005; UNEP, 2005). In Sri Lanka alone, over 40,000 people were killed and many thousands were displaced by the flood waves and the extensive

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property damage. In addition, most of the natural ecosystem along the coast was destroyed and the entire infrastructure facilities in this coastal belt were totally devastated. Immediately after the tsunami, it was estimated that over 60,000 groundwater wells (mostly dug wells) throughout the affected coastal zone and in some places almost up to 1.5 kilometers inland were damaged or destroyed. Many of them were left unable to provide water that was fit for human consumption or even fit for bathing or washing (ADB et al., 2005; UNEP 2005). The damage to the wells ranged from filling them with debris, sewage and saltwater to salt water intrusion from the stagnant saline water collected in local depressions. Many water supply schemes catering the domestic needs were also affected due to breaches in the water distribution pipelines and the filling of wells with debris and saltwater. In addition, the characteristics and quality of soil and water resources in the coastal areas were changed by the flow of seawater over the soil surface, the stagnation of saline and possibly polluted water in local depressions and the disruption and loss of the coastline. According to a study by Jayaweera et. al., a few days after the tsunami, the contaminated wells had COD levels of 128 mg/l, total and fecal coliform levels exceeding 30 and 7pfu/100ml, and conductivity levels of over 3000 µS/cm.

The two most common methods adopted to clean up wells soon after the tsunami was to empty the contaminated water either by means of pumping or by manual cleaning and disinfection using bleaching powder (hypochlorite). These restoration effects encountered a range of problems, as most of the people involved lacked specialized knowledge. Most of the cleaned wells were reported to remain saline, even after repeated cleaning and emptying. In addition, wells collapsed during the cleaning process, and the presence of contaminants from other sources of pollution potentially caused health hazards that previously did not present a significant problem (Jayaweera et al. 2005; Villholth et al. 2005). These experiences made very clear the necessity of a well-coordinated integrated plan to restore the groundwater after the effects of the tsunami and to implement relief measures. In this regard, the IWMI, through some monitoring (Villholth et al. 2005), has suggested a set of possible guidelines to follow with respect to the cleaning of wells after a tsunami. The guidelines include short-term as well as long-term measures.

4. Policy Responses and Future Challenges

Though Sri Lanka is blessed with good water resources when one considers the total aggregate water availability, the variations over space and time, from the historical perspective, demand a proper management strategy. However, there have been a number of recent warning signals pointing to increasing water resource issues in Sri Lanka. Competition and water shortages are increasing as a result of the highly variable rainfall and growing demand for water. Watersheds are being degraded, resulting in soil erosion, the sedimentation of reservoirs, landslides and more serious floods and droughts. Water pollution from domestic, agricultural and industrial sources is contaminating the surface water and groundwater and affecting the environment and public health. Excessive groundwater abstraction is occurring in some areas, affecting long term sustainability. With the technical assistance from the Asian Development Bank, the Government of Sri Lanka formulated the first draft of a 'National Water Resource Policy' in 2000. This proposed comprehensive water policy devoted an entire subsection to the management of groundwater resources with the objective of promoting sustainable development of the resources.

At present the Water Resources Board (WRB), National Water Supply and Drainage Board (NWS&DB) and the Agriculture Development Authority (ADA) are all engaged in investigations into and development of groundwater resources in Sri Lanka. However, none of these agencies are responsible for the management of the groundwater resources of the country, in terms of the quantity and quality aspects, and there is no legislative basis for the proper assessment planning or management of groundwater. In addition, adequate financial and human resources are also not being provided.

The major deficiencies in the present groundwater management setup that have been identified under the proposed water policy are listed below (Water Resources Council and Secretariat 2000).

- Ownership, and therefore management responsibility, of the groundwater is not clearly defined in legislation.
- Responsibility for investigation into, development of and regulation of groundwater is not formally assigned to any agency. A number of agencies are involved in various aspects of groundwater investigation and development as a consequence of other mandates. In

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some cases, there is no proper legal basis.

- There is no coordinated groundwater information program. Many studies have been undertaken and considerable data exists, but it has not been consolidated and is not being used to any great extent in management decisions.
- Even when a considerable body of information on seasonal behavior and quality is available, there is no institutional authority for control or regulation of the resource.
- There is no groundwater planning system. Problems and issues are being dealt with on an ad hoc basis. The vital linkage between surface and groundwater is being largely ignored and the consequences of the lack of groundwater regulation are affecting surface water management.
- There is no legal basis for groundwater allocation. Being an essentially unregulated resource, groundwater is being exploited in a haphazard and, in some cases, hasty manner, Excessive groundwater abstraction is occurring in some places, with significant costs for existing (and sometimes vulnerable) users.
- There is no public information or awareness program regarding groundwater. The resource is widely misunderstood, even by decision-makers. Although there is significant local impact due to the lack of groundwater management, local stakeholders bias the information and means of involvement.

However, during this study, several issues were identified as urgent challenges to be immediately addressed. Among those, the most important issue is the establishment of a single authority responsible for overseeing management of the groundwater resource. As there are several agencies involved in groundwater development, nobody takes responsibility for managing the groundwater resources. Often, this has been the main reason for the present groundwater problems.

Some of the observed groundwater problems in the recent past suggest that groundwater development in Sri Lanka has now reached a stage where it is useless to speak of sustainable development of the country' s groundwater resources without a supporting research effort to diagnose and troubleshoot both existing and emerging problems, and without properly managing and guiding the ongoing groundwater activities in the country. Therefore another prime need at the present stage is the establishment of an appropriate research plan to promote both short and long-term research and investigations programs. Funding for this may come by establishing a fund through levying a groundwater charge for heavy uses. Further, as there are no present programs available for either monitoring the changes in the quality or quantity of groundwater, the actual state of groundwater in the country is very uncertain. Therefore, in the absence of these information sources, establishing a proper monitoring network and using it as a comprehensive and reliable information system is essential. Without this initiative, the groundwater resources of a country is often poorly understood and over-exploited by both the decision-makers and the users of the groundwater.

At present, information about groundwater resources in this country is not readily accessible. There is no coordinated groundwater information program, although some studies have been undertaken in the past. This data has not been consolidated, and even in its scattered form, it is not used to any significant extent in management decisions. Therefore, through publications that possibly come out periodically, the presently available information on the different aquifers and the management issues need to be taken to the general user and managers at the district level in a readily understood manner. The information should be easy to understand to increase awareness and to obtain support in managing the resources. Also, guidelines for the safe and sustainable use of groundwater should also be framed for all types of aquifers in this country. The guidelines should be widely disseminated to both the local and district provincial agencies and other end-users.

5. Proposed Policy Recommendations

1. Establish principles for groundwater management through an awareness of natural replenishment rates and through an identification of the long-term damage arising from pollution or depletion, thereby minimizing resource depletion. To achieve sustainable management of groundwater resources, the unique characteristics of specific aquifers need to be recognized. In particular, the rate of aquifer replenishment and the sensitivity of aquifers to depletion and contamination need to be taken into account in groundwater planning and allocation.
2. Establish a single authority for the management of groundwater resources and make that agency responsible for the coordination and the

decentralizing all issues related to groundwater management thereby enhancing the information on groundwater resources.

3. Issue guidelines for the safe and sustainable exploitation and use of groundwater for all types of aquifers in this country. Disseminate the guidelines widely. Drilling technology needs to be improved and needs to set standards for drilling companies.
4. Initially, start a registration program for heavy groundwater users. Thereafter, establish a well licensing program to track groundwater development.
5. One main reason for the failure of the proposed water policy in Sri Lanka in 2000 was the poor level of consultation with the stakeholders. Therefore, it is necessary to have strong participation from the community and water users, and to promote awareness to facilitate the planning and management of groundwater resources.
6. Surface and groundwater resources need to be managed and allocated in a fully coordinated manner.
7. Areas sensitive to groundwater should be identified and demarcated with immediate effect.
8. An integrated approach should be taken in the management of surface and groundwater. This may involve education and other means of encouraging water users to use surface water when it is available and to save groundwater for use during periods when there is deficient surface water.
9. In most cases, the exploitation of shallow groundwater is through small-scale domestic and agricultural wells. While each of these wells use only a small amount of water, their cumulative impact can be considerable. It is considered impractical to regulate these small wells through water entitlements. Therefore steps must be taken to somehow control the over-use of shallow aquifers and thus to safeguard the water supplies of existing users of shallow wells.
10. Reliable information is essential for the sound management of water resources. However, information on groundwater availability and quality is currently very limited and it is necessary to enhance the collection of groundwater data and management of information.
11. A strategic approach needs to be adopted in relation to groundwater information. Research, assessment and ongoing monitoring need to be undertaken both on a widespread, reconnaissance basis and more intensively, in priority aquifers and in areas of declared water management and areas sensitive to groundwater.

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PART Ⅲ

Groundwater Resource Management in Bangkok

Mukand Singh Babel, Ashim Das Gupta, and Niña Donna Sto. Domingo

1. Background of the Study Area

The Case Study focuses on the groundwater resources management situation in the seven provinces of Bangkok, Nonthaburi, Samut Prakan, Pathumthani, Samut Sakhon, Nakhon Pathom, and Ayutthaya, which comprise the region considered as the economic and political center of Thailand, and where groundwater is most extensively exploited.

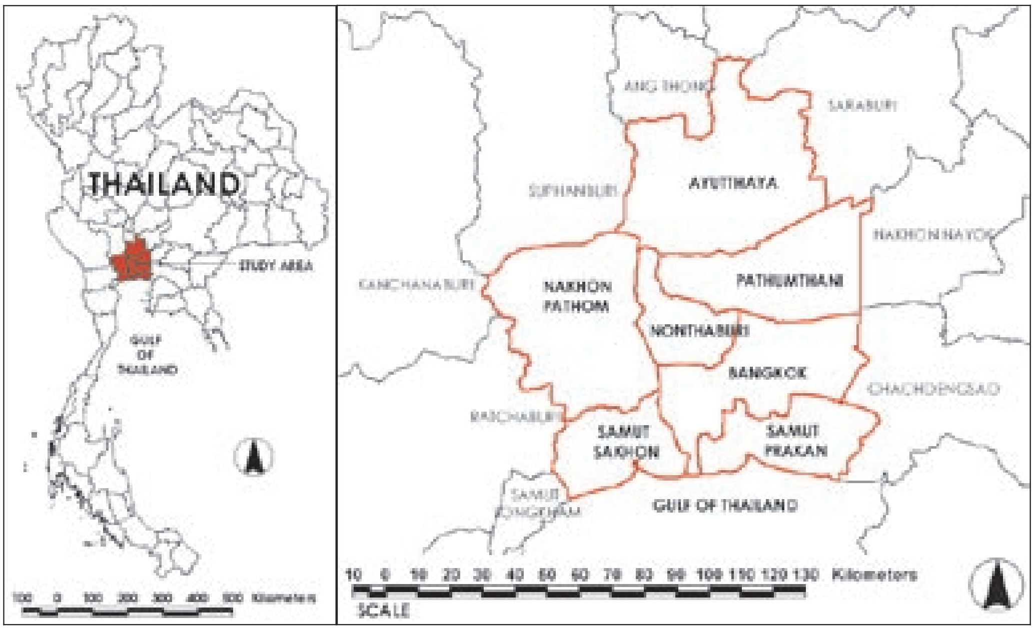

Figure 1. Thailand Case Study Area

Soft to stiff dark gray to black clay, also known as "Bangkok Clay," ranging in thickness from 20-30 m makes up the topsoil layer of the Study Area. Beneath the Bangkok Clay layer are unconsolidated and semi-consolidated sediments intercalated by clay layers and containing large volumes of voids for water storage, which form several confined aquifers that are distinguished into eight layers as: (1) Bangkok Aquifer (50-m zone), (2) Phra Pradaeng Aquifer (100-m zone), (3) Nakhon Luang Aquifer (150-m zone), (4) Nonthaburi Aquifer (200-m zone), (5) Sam Khok Aquifer (300-m zone), (6) Phaya Thai Aquifer (350-m zone), (7) Thonburi Aquifer (450-m zone), and (8) Pak Nam Aquifer (550-m zone) (AIT 1982).

The total population in the Study Area in 2003 was about 10.6 million. With a total land area of about 10,300 km^2, the average population density in the Study Area was about 1,000 people per square kilometer at that time. The population in Bangkok makes up more than half of the total population in the Study Area. The total Gross Provincial Product (GPP), or the value of all final goods and services produced within a province in a given year, in the Study Area in 2002 was 2,661,167 million Baht (at current prices), which accounted for approximately half of the country's GDP, and 72 % of which was generated in Bangkok.

The climate in the Study Area is humid and tropical. With rainfall amounts varying from 1,000 mm (in Pathumthani) to 1,300 mm (in Bangkok), the mean annual rainfall in the area is around 1,120 mm. The Study Area is situated in the southern part of the Lower Chao Phraya River Basin in Central Thailand, and comprises about 30% of the Basin, which is around 34,000 km^2 in area (Kasetsart University 1998). In 1996, total water demand in the Lower Chao Phraya Basin was estimated at 17,500 million m^3/yr consisting of 16,900 million m^3/yr surface water and 600 million m^3/yr groundwater. By 2016, it is estimated that this amount will increase to more than 18,000 million m^3/yr, comprised of 17,400 million m^3/yr of surface water demand and 800 million m^3/yr of groundwater demand (RID 2000).

A large portion of Thailand's water resources is used for agriculture. According to Royal Irrigation Department (hereafter RID), the total amount of water used for irrigation in the Lower Chao Phraya Basin in 1996 was 12,747 million m^3, which was more that 70% of the total water demand in the basin at that time. RID further estimates that agricultural water use in the basin would slightly increase to 12,780 million m^3 in 2006 (RID, 2000). The second highest use for water in the country is for domestic consumption. RID estimates indicate that the domestic water consumption (surface and groundwater) of 2,362 million m^3/yr in 1996 in the Lower Chao Phraya River basin will increase by about 9% in 2006 and 14% in 2016. Accounting for only 2% (or 1,312 million m^3) of estimated total water withdrawal in Thailand in 1993, the industrial sector is a relatively small user of water compared to the agricultural sector, which accounted for 92% (or 48,172 million m^3) of the country's water consumption in the same year. However, it is estimated that in the future, water use for agriculture will level off while that for industrial use will continue to grow rapidly. According to estimates, industrial water use in the Lower Chao Phraya Basin (combined with water demand for tourism) amounted to about 1,097 million m^3/yr in 1996, and that this will increase by about 22% to 1,335 million m^3/yr by 2006 and by 34% to 1,469 million m^3/yr in 2016 (RID 2000).

The Metropolitan Waterworks Authority (MWA), and the Provincial Waterworks Authority (PWA) are the two main water supply service providers in Thailand. MWA supplies water to Bangkok, Nonthaburi, and Samut Prakan, while PWA is responsible for supplying water to the other remaining provinces in the country. The area of responsibility of MWA is around 3,200 km^2, and in 2003, MWA water service covered 1,515 km^2 of the area with the number of connections reaching 1,540,203. Although only around 47% of the total area of responsibility was covered by MWA in 2003, the number of people served was approximately 89% of the total population in the area, which was about 7.8 million at that time. Four of the seven provinces in the Study Area—Ayutthaya, Nakhon Pathom, Pathumthani, and Samut Sakhon—are part of PWA's area of responsibility. Available data from PWA show a rapid increase in water production and sales in Pathumthani, moderate increase in Samut Sakhon, and slow increase in Nakhon Pathom and Ayutthaya. Service coverage has been low, most especially for Nakhon Pathom and Ayutthaya, where statistics show that PWA supplies water to only about 2-3% of the population in both provinces. In Samut Sakhon, the percentage of residents receiving water services from PWA has increased from 3% in 1997 to almost 6% in 2003. In Pathumthani, a larger portion of the population (11% in 1997 to 15% in 2003) compared to other provinces receives PWA water supply services.

2. Groundwater use and its Associated Problems

In Thailand, groundwater is primarily developed for domestic and industrial purposes, and used only as a supplement for surface water irrigation by the agricultural sector. Of the eight layers comprising the aquifer system in the Study Area, the second (Phra Pradaeng), third (Nakhon Luang), and fourth (Nonthaburi) layers from the ground surface are the most used because of their high productivity, accessibility, and the good quality of groundwater they produce. The deeper aquifers also contain groundwater of good quality but are not as popular for use because of their relatively great depths. However, exploitation of the deeper aquifers, especially for industrial use, has increased in recent years.

Available records show that extensive use of groundwater in the area began in the mid-1950s, when it was primarily used to supplement surface water for public water supply. By 1976, it was estimated that groundwater pumpage in Bangkok and in the adjacent municipalities of Nonthaburi and Samut Prakan had increased to about 937,000 m^3/d from 8,360 m^3/d in 1954. In 1968, there was a major increase in the use of groundwater for public water supply, after which public usage became relatively constant at around 300,000 to 400,000 m^3/d. It reached its peak in the late-1970s and early-1980s, amounting to 464,000 m^3/d in 1980, and then slowly declining after earnest implementation of control measures in 1983. Because the expansion of piped-water supply services by waterworks agencies lag behind urban development, private usage of groundwater has generally continued to increase. The private sector is currently the most significant groundwater user in the Study Area (figure 2).

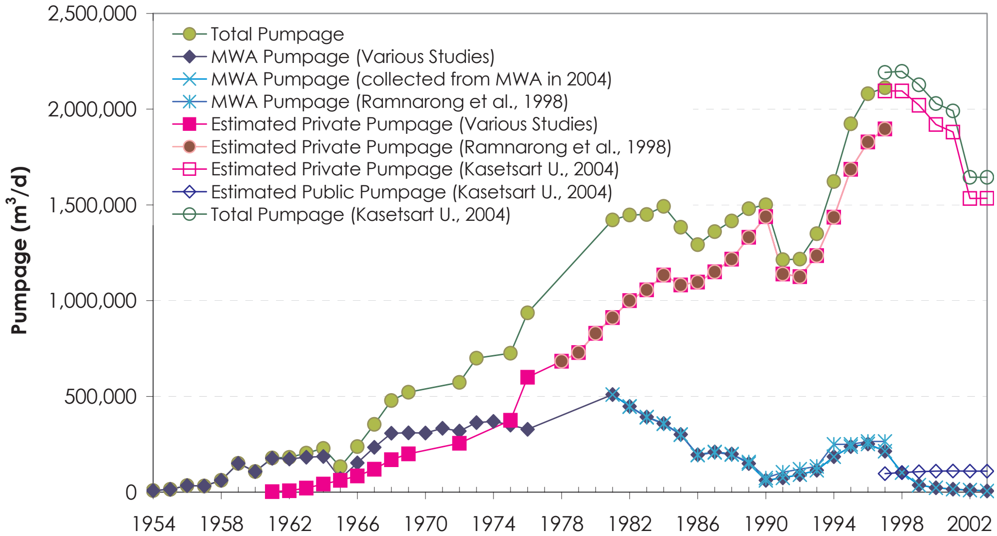

Figure 2. Groundwater Pumpage in Bangkok and Surrounding Areas

Sources: AIT and DMR, 1978; Ramnarong et al., 1998; Kasetsart University, 2004

Recent estimates of groundwater use in the Study Area indicate that total pumpage by registered private wells has been around 2 million m^3/d since 1997, varying from 2.2 million m^3/d in 1997 to 2 million m^3/d in 2001, and decreasing to 1.7 million m^3/d in 2003. Groundwater use for public supply, which is composed of groundwater use not only by waterworks agencies but also by various other government agencies, was estimated at about 155,000 m^3/d from 1997 to 2003. In 2003, the total registered groundwater use in the seven provinces of Bangkok, Nonthaburi, Samut Prakan, Pathumthani, Nakhon Pathom, Samut Sakhon, and Ayutthaya was approximately 1.8 million m^3/d, 92% of which was by private users (Kasetsart University 2004).

In Bangkok City and the surrounding provinces, excessive use of groundwater resources has caused serious environmental problems such as rapid groundwater depletion, quality deterioration, and land subsidence. Considerable lowering of the ground has occurred in many places, and observations from monitoring wells across the region indicate substantial declines in water levels in the aquifers (figure 3).

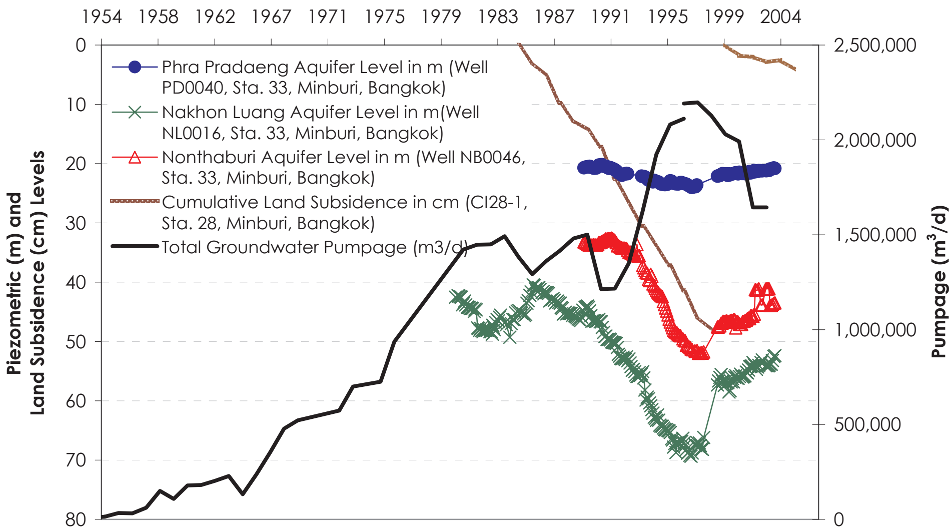

Figure 3. Total Groundwater Pumpage in Bangkok and Surrounding Areas, and Piezometric and Land Subsidence Level Variations in Minburi, Bangkok

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Land subsidence has been a continuing problem in the Bangkok region for the past four decades, and the provinces comprising the Study Area has been identified by the Department of Groundwater Resources (DGR) as Critical Zones seriously affected by groundwater problems. The occurrence of land subsidence in the Study Area has been attributed to the extensive decline in groundwater levels, which in turn is due to excessive groundwater extraction rates. In 1969, land subsidence was given widespread attention when many indications were being observed in the Bangkok area (AIT 1982). Protrusions of well casings in Bangkok indicated around half a meter of subsidence in central Bangkok in 1978 (figure 4) (AIT 1981).

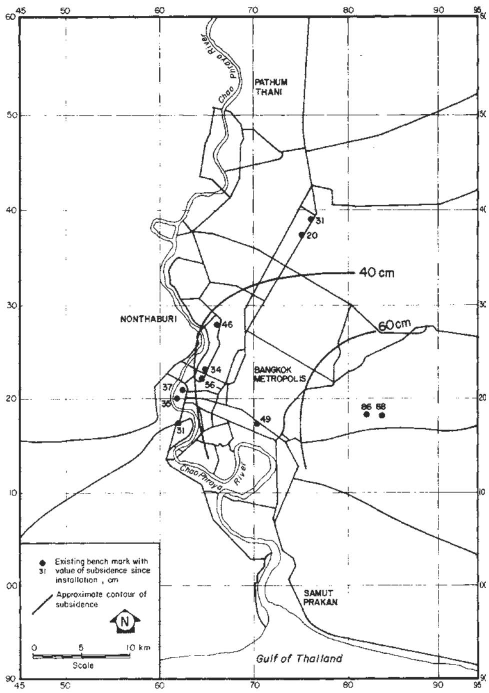

Figure 4. Subsidence in Bangkok from the First Leveling by the RTSD in 1978

Source: AIT, 1981

An investigation program initiated by of the National Environment Board (NEB) of Thailand in 1978-1981 showed irrefutable evidences of land subsidence due to deep well pumping in the Bangkok Area. It was found that subsidence rates varied from place to place, with the average rate of subsidence in Bangkok City at about 5 cm/yr. Maximum subsidence rates of more than 10 cm/yr were detected in the eastern part of Bangkok. Piezometric readings showed that the areas characterized by high subsidence rates also experienced great declines in groundwater levels, which dropped to a maximum of 40-50 m below the ground surface (AIT 1981). Land subsidence continues to occur throughout the Bangkok Metropolitan Region, although at lesser magnitudes than before (figure 5). Subsidence rates of around 1 cm/yr exist in most parts of the region. In the central, east, and southeastern parts of Bangkok City, where from 1978 to 1999 land subsidence was from half a meter to more than one meter, much improvement in the land subsidence problem has been observed in recent years. From 2001 to 2003, land subsidence in these areas has been reduced to about 1 cm/yr. Nevertheless, land subsidence is observed to be migrating to the outskirts of Bangkok City and into the surrounding provinces of Samut Prakan, Pathumthani, Nonthaburi, Samut Sakhon, and Nakhon Pathom. In the industrial province of Samut Prakan, land subsidence at rates of 2-5 cm/yr was observed in 2003, as well as in Samut Sakhon located southwest of Bangkok (Kasetsart University 2004).

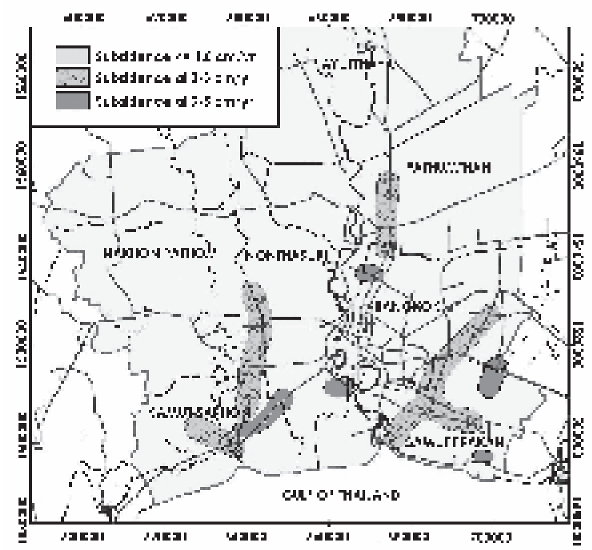

Figure 5. Map Showing Land Subsidence in 2003

Source: DGR 2005

Water levels in the Bangkok Aquifer System have been declining since the late 1960s due to increasing rates of extraction, with water levels in the aquifers dropping a total of more than 40 to 50 m. Groundwater drawdown started in central Bangkok in the late 1960s and then spread over the entire Bangkok Metropolis in the 1970s. With further increased pumping, piezometric levels in pumped aquifers declined. Records have shown that water levels went down about 5-10 m from the late 1970s to around the early 1980s. Some recovery was observed after serious enforcement of the regulations in 1983, after which, water levels started to decline once again. Groundwater levels continued to decline until the late 1990s, especially in the Phra Pradaeng, Nakhon Luang, and Nonthaburi Aquifers. The lowest groundwater levels were reached around 1997, recovering afterwards although not up to previous levels as in the late 1980s.

As for groundwater quality, recent analysis of monitoring data from DGR has shown elevated concentrations of chloride (increased salinity) for the three most popularly used aquifers (Phra Pradaeng, Nakhon Luang, and Nonthaburi) especially in areas near the Gulf of Thailand in Samut Prakan province and along the Chao Phraya River (Kasetsart University 2004).

3. Policy Responses and Future Challenges

Since the emergence of various problems associated with groundwater in the Study Area in the 1960s and 70s the government has implemented numerous measures to mitigation these problems. These policies and regulations, which are of various types, include:

A. Regulatory measures

- ***Comprehensive law for groundwater.*** A specific law concerning groundwater in Thailand came about in 1977 when Groundwater Act, B.E. 2520 (1977) was enacted (JICA et al. 1999). The Act came into effect in 1978, and it has been amended twice—in 1992, and in 2003. It contains provisions for controlling the exploration and drilling for groundwater, the use of groundwater, the recharging of aquifers through wells, and the protection and conservation of groundwater resources in the country.
- ***Designation of groundwater regions and critical zones.*** To control groundwater use and mitigate environmental problems associated with it, areas most severely affected by groundwater-related problems such as land subsidence and groundwater depletion were designated as the Critical Zones where more control over private and public groundwater activities were instituted.
- ***Licensing for well-drilling and groundwater use.*** Under the Groundwater Act, the government initiated licensing for the installation of wells and private groundwater use. Licenses were required to extract groundwater, and pumpage limits were instituted through these permits.
- ***Groundwater use metering.*** The installation of well meters was enforced in 1985 in support of the use charges that the government started to levy from private users at that time.
- ***Establishment of groundwater quality standards.*** To promote groundwater and environmental quality conservation, standards for groundwater for drinking purposes were established through the Groundwater Act, and in 2000, groundwater quality standards for the conservation of environmental quality were issued (PCD 2004).

B. Economic measures

- ***Implementation of groundwater use charges.*** Groundwater Use Charges were first implemented in 1985 in the six provinces of Bangkok, Nonthaburi, Pathumthani, Ayutthaya, Samut Prakan, and in parts of Samut Sakhon, where Bt1.00 was charged for every cubic meter of groundwater used. By 1994, the charge was increased to 3.50 Bt/m^3, and the government began to charge for groundwater use in the whole country. Between 2000 and 2003, groundwater charge was gradually increased in the Critical Zone from 3.50 Bt/m^3 (July 2000) to 8.50 Bt/m^3 (April 2003).
- ***Implementation of preservation charges.*** The Ministry of Natural Resources and Environment (MONRE), based on the 2003 amendment of the Groundwater Act, has recently imposed the Groundwater Preservation Charge for all groundwater users in the Critical Zone. Starting at 1.00 Bt/m^3 (1 September 2004), the charge is set to increase to 8.50 Bt/m^3 in 2006, leveling off at that rate beyond 1 July 2006. Because of the institution of the Charge, the total cost per cubic meter of groundwater use in the Critical Zone has become relatively high, which has helped in limiting the exploitation of groundwater in the area. Total groundwater charge is expected to increase from 9.50 Bt/m^3 in 2004, to 12.50 Bt/m^3 by mid-2005, and to 17 Bt/m^3 by July 2006 and beyond, which is deterring groundwater users in the area, especially those using large amounts such as industries, from using groundwater for their water supply.
- ***Levying surcharges and penalizing violators of regulations.***

C. Supporting Measures

- ***Groundwater monitoring system.*** The Bangkok Groundwater Monitoring Network was established under the comprehensive study programme on groundwater and land subsidence from 1978-1981, and it is used to collect data on groundwater levels, land subsidence, and groundwater quality in the

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various aquifers in the Study Area.

- ***Groundwater database system.*** The Groundwater Database System was established in 1995 through the JICA study on "Management of Groundwater and Land Subsidence in the Bangkok Metropolitan Area and its Vicinity" (JICA, 1995).

D. Other Measures

- ***Artificial recharge of aquifers.*** The government is also presently considering the implementation of technical measures to mitigate the problems due to groundwater overexploitation in the Study Area, which include artificial recharge of the depleted aquifers.
- ***Public awareness programs.*** Also, DGR has launched public awareness programs to educate the population about the proper use of groundwater resources in the country through publication of various brochures and booklets.

Fifty years of groundwater management efforts in Thailand have seen the enforcement of a wide range of measures aimed at keeping groundwater exploitation in the country under control. Although many of them have resulted in the alleviation of groundwater problems, some have been found to be not as effective as expected. Various interrelated factors hinder effective implementation of these policies and measures.

A major barrier towards proper control over excessive and illegal use of groundwater resources in the Study Area is lack of institutional thrust from concerned authorities resulting into ineffective implementation of laws and regulations. Despite the existence of laws requiring licenses for all private groundwater-related activities in the country, illegal private wells still exist. Shortage in the number of DGR Inspectors and budgetary constraints limit the authorities' abilities to ensure that all private well users are registered with DGR. Many groundwater wells remain un-metered even with the existence of a regulation requiring the installation of meters for wells more than 15 m deep. Although this regulation has allowed authorities more accurate quantification of groundwater use and has ensured that users pay for exactly how much they extract and not exceed allowable amounts, the effectiveness of this control measure has been limited by the fact that not all registered users comply with it. Although groundwater users will have to pay for the full permitted amounts (even if they actually use less) when their wells are un-metered, this has not driven them to abide by the regulations, because perhaps the existing system of groundwater-use reporting, wherein well owners report their monthly use to DGR, who in turn bills them for their consumption, does not really incite groundwater users to do so.

Lack of monetary as well as human resources add to the difficulties of the authorities in strictly enforcing groundwater management regulations, as they are unable to conduct proper monitoring of groundwater activities in the country. Regular inspections of registered wells and groundwater users could not be conducted as often as necessary, groundwater monitoring stations could not be properly maintained, and a more efficient system for metering and charge collection could not be established. The Groundwater Database System has allowed convenient access, by groundwater managers and decision-makers, to groundwater resources-related information in the Bangkok Region necessary in assessing the status of the resource and formulating proper management measures. However, the full potential of the Groundwater Database System is currently not being realized due to lack of maintenance and updating. Budget constraints have also hindered the regular maintenance, rehabilitation, and expansion of the Groundwater Monitoring System, which has enabled the collection of important information about the aquifers as well as the land subsidence situation in Bangkok and surrounding provinces.

Some inappropriate legislation may also be considered as hindrances to effective implementation of regulatory measures. For instance, the legal definition of groundwater as being water occurring beneath the ground at depths exceeding 15, 20, or 30 m (depending on the region in the country), which still stands today even after two amendments of the Groundwater Act, keeps the use of groundwater from shallow aquifers all over the country largely unregulated. Also, groundwater use charges are not levied for agricultural groundwater use. Furthermore, although ignorance of the law is never a good reason for not following it, some groundwater users are just truly uninformed of the regulations for using groundwater resources in the country. Furthermore, perhaps lack of discipline of groundwater users, which may be further encouraged by the weak resolve of the authorities to enforce regulations and impose penalties, is another factor that hinders the strict implementation of groundwater management measures in the country and in the Study Area. Punishment for lawbreakers range from a fine of not more than Bt 20,000 to six months of imprisonment, and penalties are charged for late payment of groundwater charges, but the effectiveness of penalties and fines imposed upon violators of regulations has been limited possibly due to the relatively meager fines and that inspections for discovering violations and enforcing the penalties are not conducted enough.

Finally, possibly one of the most serious barriers to effective implementation of existing policies and the introduction of improved measures is lack of alternative sources of water that are suitable for the needs of industries, which are the largest groundwater users in the Study Area. Sufficient and reliable piped-water supplies for domestic consumption are also lacking, especially in areas located far from city and town centers, such that private business and homeowners have no other option but to develop groundwater resources for their water supplies. This also limits the effectiveness of levying charges for groundwater use in controlling private groundwater abstraction since without alternative sources of water consumers have no choice but to continue using groundwater despite increased costs.

With the introduction of new ideas and concepts such as effective resources use and integrated water resources management, the formerly supply-driven approach to groundwater resources development and management in Thailand has been shifting towards management based on scientific/academic knowledge. Project studies have been initiated and conducted in recent years as the responsible authorities (DGR) seek to better understand and learn more about the occurrence of groundwater resources and its associated problems in the country.

4. Proposed Policy Options for Sustainable Groundwater Use

In the Stakeholders Meeting conducted in July 2005, policies and measures for the mitigation of groundwater-related problems and improving groundwater resources management in the Study Area were drafted. The recommendations included direct control, economic, supporting, technical, and informative measures such as:

- ***Firm implementation of regulations.*** Illegal use of groundwater may be curbed through institution of stiffer penalties and at the same time ensuring that proper mechanisms for enforcing these penalties are in place. Another approach would be for DGR to pardon currently unregistered groundwater users and ask them to register with the authorities afterwards.
- ***Stricter limits on industrial water/groundwater use.*** Reduction of water/groundwater use by the industries may be advanced through provision of incentives for recycle and reuse of water as well as the promotion of clean technologies.
- ***Relocation of large groundwater users, such as industries, outside the Critical Zone.***
- ***Establishment of an authority that will extract groundwater for water supply.*** Increased control over groundwater extraction without actually curtailing its use may be achieved through the establishment of an agency that will extract groundwater and supply water in the Study Area.
- ***Further increase of Groundwater Use Charges.*** With the implementation of Groundwater Preservation Charges in the Study Area, total charges for groundwater have become more comparable with public water supply rates, such that the impact of further increasing groundwater use charges in terms of lessening groundwater use will now be more marked.
- ***Charging for agricultural groundwater use.*** It was also suggested that agro-wells, which are currently exempted from paying Groundwater Use Charges, now be charged for groundwater use.
- ***Modifying Groundwater Preservation Charge rates.*** A flat rate for Groundwater Preservation Charge is currently in place in the Study Area. It was suggested that a study be conducted to develop a progressive Groundwater Preservation Charge rate based on use amounts and the groundwater resources conditions in each area. In addition, groundwater stakeholders in the area should be better informed of the purposes and objectives for collecting Groundwater Preservation Charges.
- ***Implementation of Polluters Pay Principle (PPP).***
- ***Establishing a groundwater market.***
- ***Artificial recharge of aquifers.*** Increasing groundwater recharge through artificial and natural means to facilitate recovery of piezometric heads in the aquifers was also proposed. Although several projects have been conducted about the feasibility of artificial recharge in the Study Area, it is yet to be implemented by DGR. Recharging water into aquifers through a system of wells will not only help increase piezometric levels, it will also assist

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in mitigating saline water intrusion by creating a freshwater barrier protecting the groundwater.

- ***Encouraging public participation.*** The public must be made aware of the groundwater situation in their areas, and they must be given opportunities to actively participate in the development and enforcement of solutions to problems resulting from groundwater use.
- ***Updating/redefinition of the Critical Zone.*** Updating of the Critical Zone in accordance with the master plans of MWA and PWA must be considered for more reasonable and realistic implementation of mitigation and control measures in the Study Area.
- ***Improving monitoring of groundwater activities.*** A good system for regular inspection and monitoring of groundwater wells in the area must be established. Regular inspections must be conducted to prevent illegal well drilling and the use of groundwater without the use of meters, and authorities must be firm at meting out punishments to violators. These targets may be achieved through the involvement of the private sector in groundwater use monitoring and charge collection. The industries themselves may also assist the authorities in establishing the telemetry system, which will help in monitoring abstraction by large users of groundwater.
- ***Improving Groundwater Monitoring and Database systems using the Groundwater Development Fund (GDF).*** The GDF may be used to improve and maintain the groundwater monitoring and database systems, and for establishing a telemetry system. However, present regulations make it difficult for stakeholders and even DGR to use the GDF. Thus, the amendment of the Groundwater Act or relevant regulations regarding the use of the Groundwater Development Fund may be required. Regular data collection must be conducted to update and maintain the Groundwater Database System at DGR. Data consistency must be ensured, and access to the database by groundwater managers and users alike must be improved. Links between stakeholders and authorities in terms of database use and information exchange must be established, and data exchange between provincial and central groundwater offices must be enhanced for regular updating of the database.
- ***Development of alternative water sources.*** The Thai government may also develop alternative water sources to supply water to industries, which are the biggest users of groundwater in the Study Area.
- ***Water demand management.*** Instead of further developing supplies, the authorities may promote water demand management, which involves the judicious and efficient use of water. Systematic use of the resource and/or the conjunctive use of groundwater and surface water may be promoted to minimize groundwater extraction.
- ***Capacity-building for national and local groundwater managers.*** Local groundwater management capacities must be developed, possibly through the conduct of seminars and trainings, because it is anticipated that groundwater use will continue to increase in the future, and that problems will continue to occur unless proper controls are implemented.
- ***Conduct of further studies about groundwater management issues.***

Ensuring that proposed new or improved measures are developed based on sound technical, scientific, and socio-economic information, is vital for effective implementation of policy improvements for sustainable groundwater resources management in the Study Area. Also, it is essential that the authorities obtain the cooperation of groundwater users in the Study Area to make sure that they respect and abide by promulgated regulations. Most importantly, proper implementation of improved policies for groundwater management in the Study Area requires the dedication and commitment of responsible government agencies as promulgation of recommendations into actual national laws and policies requires much time and effort from the concerned authorities.

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PART III

Groundwater Resource Management in Ho Chi Minh City

Nguyen Phuoc Dan, Bui Xuan Thanh, Le Van Khoa, and Bui Dan Truong

1. Background of the Study Area

Ho Chi Minh City (hereafter HCMC) is situated in the South of Vietnam, and is the biggest city in Vietnam. HCMC has an area of approximately 2,094 square kilometers. It is located from 10 10’-10 38’ North and 106°2’-106°54’ East. HCMC is 1,730km from Hanoi by land and is at the crossroads of international maritime routes. The city center is 50km from the East Sea in a straight line. It is a transport hub of the southern region and having the largest port system and airport in Vietnam. It is also the biggest centre of cultural, social, trading and economic activities, as well as the key area for technology and international communication activities in the whole country. Its population was 6,117,000 in 2004. Natural population and migration growth was 1.15 and 1.2%, respectively. Growth rate of industry/construction and foreign-invested sector were 112 and 113, respectively. A map of the core area of Ho Chi Minh City is shown in figure 1.

There are now more than 150,000 wells exploited for

Figure 1. Map of Ho Chi Minh City

drinking and industrial purposes in HCMC. Total used groundwater quantity is estimated about 530,000 m^3/day, of which 100,000 m^3/day is supplied for drinking purpose. Department of Science, Technology and Environment (DOSTE) of HCMC (2001) reported that current exploitation rate of all three aquifers has reached to limited value (about 500,000 m^3/day). This results in the high descent of water table. It was observed that the water table has been lowered by 4 – 5 m during the last 5 years in Thu Duc and Go Vap Districts.

2. Water use

2-1. Public Water Supply

The water supply system of HCMC, built in 1879 (the French colony) and have been improved several times. Saigon water treatment plant located in Thu Duc District was set-up and run at the capacity of 480,000 m^3/day in 1966. Thu Duc water treatment plaut has been upgraded several times and the present capacity is 750,000 m^3/day. Hoc Mon groundwater treatment plant with capacity of 60,000 m^3/day was started running in December 1993.

The socio-economic development plan of HCMC People's Committee for period 2001–2020 (VIWASE 2004) shows that the quantity of piped water increases to 1,670,000 m^3/day; 2,180,000 m^3/day and 3,290,000 m^3/day in the year 2004, 2010 and 2020, respectively.

2-2. Rain Water Utilization

In Can Gio District, rain water is one of the main domestic water resources. Every month, ship transports 5000 m^3 from HCMC to Can Gio so water demand is about 3 - 4 l/capita.day. HCMC's water supply company is planning to install water network for this area through the route of Nha Be – Can Gio districts.

2-3. Groundwater

Three of five aquifers in HCMC territory play important role in water supply for HCMC, namely, Pleistocene aquifer (20–50m); Upper-Pliocene (50–100m) and lower-Pliocene aquifer (100–140m). At present, there are more than 150,000 wells exploited for drinking and industrial purposes in HCMC (Chan 2004). The Union for Geology No.8 (2001) assessed that the sustainable groundwater use limit rate of all three aquifers was about 500,000m^3/day.

The ratio of groundwater exploitation will be 21 % of the total in year of 2010 and 15% in year of 2020. Groundwater is currently important resource for the development of the city for now (32–42% of water supply) and will continue to be in future. In practice, water table descent has been observed in some monitoring wells. Furthermore, the groundwater is under threat due to contamination of the shallow aquifer (Pleistocene) and over exploitation of domestic and industrial wells.

PART III

3. State of Groundwater and its Associated Problems

3-1. The Exploitation Rate

Groundwater in HCMC has been exploited for domestic and industrial uses from the beginning of 20th century. The survey of Department of Industry (2000) reported that HCMC had 95,828 wells with the different diameters and depths at the end of 1999 and about 150,000 wells, equivalent to over 530,000 m^3/day, in 2003 (Nga 2004). The number of wells exploited in the aquifer is presented as follows:

Holocene aquifer: There were over 60 wells (about 120 m^3/day) located mostly in Can Gio District. This aquifer has small water reserve and only been exploited for household uses.

Pleistocene aquifer (20-50 m deep): There were over 120,000 wells (over 277,000 m^3/day), in which included about 20,000 wells in the Upper Pliocene aquifer and 5 wells in the Lower Pliocene aquifer. The groundwater is fresh, with low pH and higher iron and ammonia.

Pliocene aquifer (40-80 m deep for the Upper Pliocene and 50-100 m for the Lower Pliocene): A lot of big industrial wells are located in this aquifer with capacity over 245,000 m^3/day.

Most of wells in HCMC are in the Pleistocene aquifer and Pliocene aquifers (99.9% total number of surveyed wells). These wells are mainly located in the inner districts and some suburban districts. Figure 2 shows that the groundwater exploitation rate has increased with time.

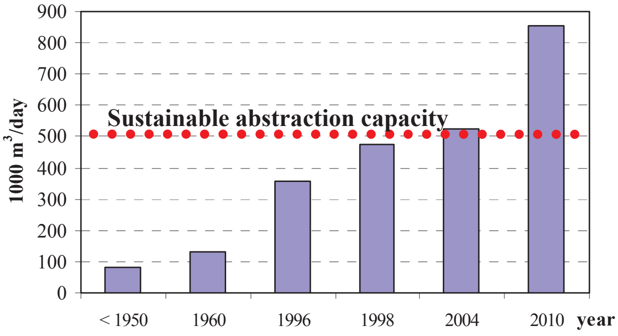

Figure 2. The Exploitation Rate with Time

3-2. Water Table Monitoring

There are two monitoring networks in HCMC: National one and local one which included 88 monitoring stations, including 3 wells in the Holocene aquifer, 37 wells in the Pliocene Aquifer, 31 wells in the upper Pliocene and 14 wells in the lower Pliocene aquifer. The monitoring results of water table from the data of national and local monitoring stations were shown in the following section.

The Pleistocene aquifer (QI-III)

The average static water table is in the range of 6.79-24.98 m. In general, the static water table is shallow and changing with season and tide. This aquifer has been used mostly for irrigation.

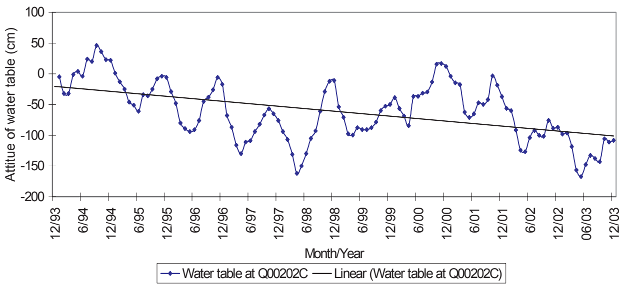

Figure 3. Change of Water Table with Time at Monitoring Station Q00202C (Cu Chi)

Along with North-west to South-east and from West to East, the water table was close to the ground surface and tends to lower gradually and the biggest descent occurred at 05A (Phu Tho, District 11). In comparison of the water table in April 2001, the one in April 2003 was significantly lowered. The water table tended to lower gradually, 22cm/year in 2002-2003.

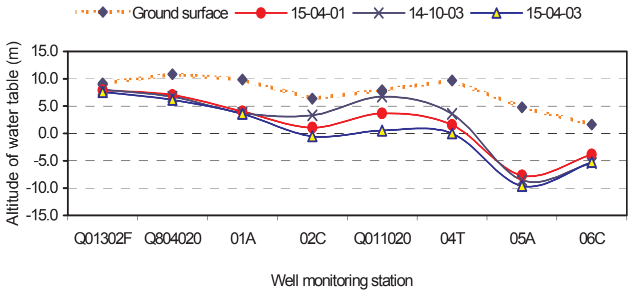

Figure 4. Water Table Profile of QI-III Aquifer along with NE– SW line

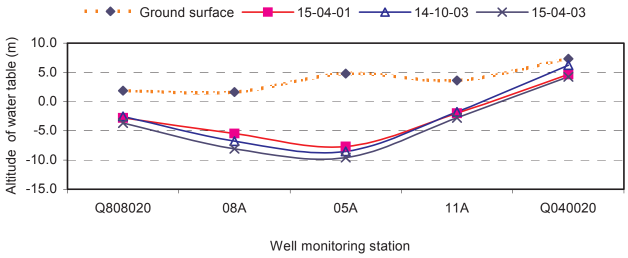

Figure 5. Water Table Profile of QI-III Aquifer Along with West - East line

The upper Pliocene aquifer (N_2^b)

The average depth of static water table is 21.2-27.7 m and 27.7 m. The result of water table monitoring during 1994 – 2003 in this aquifer shows that at the stations Q007, Q015030 (Binh Chanh); Q011340, Q017030, Q004 (Hoc Mon, district 12) the water table descended annually at the average of 0.11- 1.95 m deep. This fast descent of water table is due to excess groundwater exploitation and the water recharge in this aquifer mainly comes from rain water (see figure. 6).

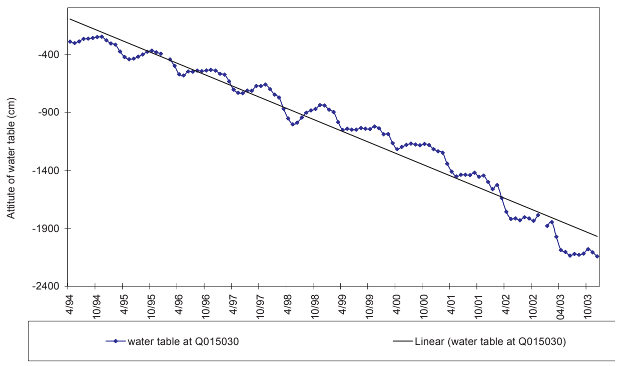

Figure 6. Change of the Water Table with Time at the Q015030 (Binh Chanh)

Along the direction from North-west to South-east and from the West to the East, the water table changed slowly in Cu Chi, Hoc Mon and had tendency of descent as to the city center.

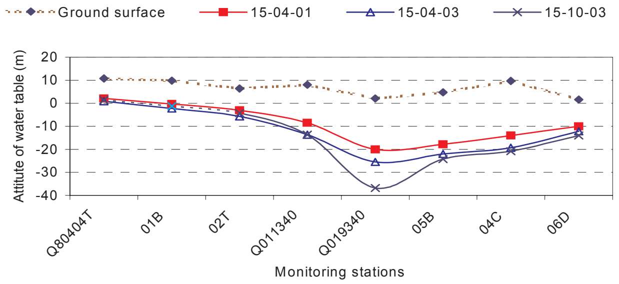

Figure 7. Graph of water table with NW – SE (Layer N_2^b)

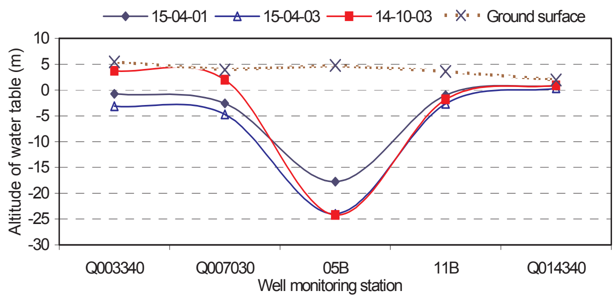

Figure 8. Graph of water table with W – E (Layer N_2^b)

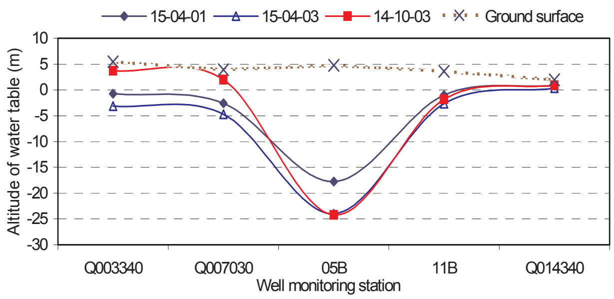

Figure 9. Change of the Water Table at the Q011040 Well Monitoring Station

The lower Pliocene aquifer (N_2^a)

In general, the static water table of this aquifer is similar to that of the upper Pliocene (N_2^b). The monitoring data from 1994-2003 shows that the water table descended annually at the average depth of 0.3 m and 1.4 m at Station Q011040 (Hoc Mon) and Q80404Z (Cu Chi), respectively. It may be due to excess groundwater exploitation (see figure 9).

3-3. Groundwater Quality

Among the 11 monitoring wells, which were set-up under the DOSTE/UNDP project – VIE 96/023 during the 1st half of 2001, there were 6 of them that have recorded nitrogen and pathogen-related contamination (nitrate, ammonium and coliform), in comparison to standards in TCVN 5944 – 1995 (Groundwater quality standard), salt intrusion and pathogen contamination exceeded standard values for 2 of 11 wells. Iron concentration of groundwater in HCMC is higher than that of the drinking water quality standards (0.3 mg/L). pH of most of surveyed wells is also lower than that of the Standards (pH < 6.5). The iron concentration in the lower Pliocene aquifer is higher than that of the other aquifers, especially in Cu Chi, Binh Chanh District.

Heavy metals (Cu, Pb, Zn, Hg, Cd, Se, Ni and As) were not detected in all aquifers. Although Phenol and Cyanua concentration were still meet groundwater quality standards, it intends to increase with time and will be continued monitoring in the future. The coliform contamination happened at some monitoring wells in the Pleistocene aquifer in 2002.

4. Policy Measures and their Effectiveness

Groundwater management in HCMC is weak. Economic instruments (e.g. groundwater exploitation fee, regulation on limitation/prohibition of groundwater exploitation) have not applied until now. A summary of the existing regulations is depicted in table 1.

Table 1. Summary of the policy measures applicable to groundwater management

Regulation	Status
Guideline on strengthening of management of groundwater exploitation and trade of well drilling	(Under consideration of HCMC PC)
Regulations on water resources management in HCMC	Issued
Regulations on limitation or prohibition of ground water exploitation in HCMC	Being compiled by DORNE
Draft guidelines on collection of resources tax in HCMC based on the Ordinance of Resource Taxes of Ministry of Finance	(Under consideration of HCMC PC)
Draft regulation on collection of groundwater exploitation fee in HCMC	Under compilation by DORNE

HCMC Department of Natural Resource and Environment (DONRE) (2001) addressed the strategy on water resource management in period 2001-2010. The main objectives of the strategy for improvement of water resources quality and management are:

- To protect groundwater resource by reduction of the exploitation rate to the value of 520,000 m^3/day in 2007 and below 500,000 m^3/day by 2010. Raising of awareness and strengthening of the regulatory framework of groundwater management will be focused.

- To improve the quality of surface water of the Dong Nai & Sai Gon rivers upstream. The water quality should be improved in 2007 as good as that of the year 2000 and reached to meet National Standard TCVN 5942–1995–A by the year of 2015.

In order to implement the strategy objectives on protection of groundwater resources, the following action plans were proposed:

1. *Identification of sustainable groundwater exploitation rate*
2. *Maintenance and expansion of the groundwater monitoring program*
3. *Establishment of proper charge on groundwater use and management structure for implementation*
4. *Expansion of piped water network*
5. *Development of central water supply system with small capacity*
6. *Implementation of control and monitoring of groundwater exploitation rate by installation of water-meters for wells used for industrial uses*
7. *Implementation of pollution controls for groundwater pollution sources*

Legal framework and organization to implement the strategy can include:

- Structure of implementation: periodically monitoring, enforcing monitoring, so on.
- Proper costing of groundwater resources,
- Set-up of funds for environmental improvement from groundwater use charges.

In order to implement these action plans on groundwater resources management, HCMC set-up ten groundwater monitoring stations, which include 28 wells located in all HCMC. The monitoring works are measurement of groundwater table, groundwater and soil sampling and analysis.

The Office of Mineral and Water Resources Management of DONRE, the Department of Transportation and public Works (DTPW) and Ho Chin Minh Water Supply Company annually co-ordinate for appraisal of projects concerning groundwater survey and exploitation before submitting to HCMC People's Committee to approve permit. There were about 60 projects appraised in 2004. HCMC's DONRE is responsible for inspection of certificate/license of trade of well drilling and groundwater exploitation. As a result, about 700 enterprises in HCMC were inspected in 2004. The organization structure of water resources management is shown in figure 10. Office of Minerals and Water Resources Management (OMWRM) is responsible for whole groundwater management in HCMC. Department of Industry (DI) is responsible for management of groundwater use for industry in the City. Department of Agriculture and Rural Development (DARD) is responsible for management of groundwater use for agriculture and rural area in the City.

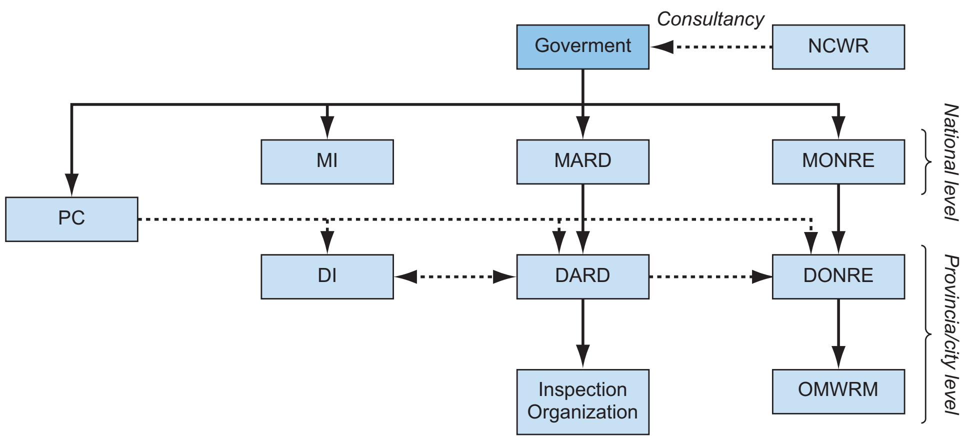

Figure 10. The Organization Structure of Water Resource Management

Note: PC - People's Committee, MI- Ministry of Industry, DI- Department of Industry, MARD- Ministry of Agriculture and Rural Development, MONRE: Ministry of Natural Resources and Environment OMWRM: Office of Minerals and Water Resources Management

PART III

5. Future Perspectives on Groundwater Resource Management

Based on water demand and population in the future, the water consumption for domestic use will be 1,046,700 m^3/day in 2010 and 1,600,000 m^3/day in 2020 and the total water demand in 2010 and 2020 will be up to 1,600,000 m^3/day and 2,400,000 m^3/day, respectively. Similar to the total water consumption in the future, groundwater use will rapidly increase in the near future because it is still free of charge at present and piped water network is not available for new residential areas.

In order to minimize the groundwater exploitation rate, expansion of surface water uptake from Sai Gon -Dong Nai rivers will be necessary. The predicted capacity of Sai Gon and Dong Nai water treatment plants will be 992,000 m^3/day in 2010 and 1.902.000 m^3/day in 2020. In order to obtain sustainable ratio of groundwater use, all governmental organizations are responsible for co-ordination to implement the proposed action plans of strategy of groundwater management in HCMC. To ensure efficient implementation, HCMC has to look for funding from:

- Sponsorship or incentive loans from other countries and international organizations;
- HCMC annual budget for environmental protection;
- Voluntary enterprises and individuals, making incentive policies for industrial production in terms of environmental protection, privatizing waste management services and;
- Environmental charges and fees for exploitation and utilization of natural resources.

6. Proposed Policy Options

To achieve sustainable groundwater management in HCMC, there are some more proposed policy options generated from stakeholder meeting on 28 September, 2005 in HCMC. It includes main aspects such as current problems with groundwater, sustainable groundwater use, protect and recharge groundwater, development of alternative water resources, measures to protect groundwater resources and achieve sustainable groundwater use and short-term measures. Department of Minerals and Groundwater Management suggested 5 measures for sustainable management:

1) Legal measures:

- to issue water resources regulation for HCMC;
- to issue regulation of limiting and prohibiting groundwater abstraction in HCMC;
- to issue regulation of wastewater discharge area, protection measures for waste treatment area.

2) Planning measures:

- to establish master plan for water resources management to 2010 orienting up to 2020 including following items:
- to estimate safety abstraction rate of water resources;
- to determine water use demand of the city till 2010 and 2020;
- to determine where can be supplied by surface water, ground water and mixtures of both sources;
- to establish and implement project: rainwater use management.

3) Economic measures:

- Water resources tax collection;
- Regulation on groundwater abstraction fee.

4) Technical measures:

- Widening groundwater monitoring system;
- Forming surface water monitoring stations in HCMC;
- Forming land subsidence monitoring station at high abstraction rate area;
- Research on salt intrusion to aquifers; determination of nitrogen sources, arsenic sources causing groundwater pollution; Assessing impacts from industrial, agricultural activities and waste treatment areas to groundwater resources.

5) Other options:

- Managing water resources through both administrative border and catchments.
- Attracting human resources and encourage citizens on water resources research, abstraction and protection.
- Taking an advantage of financial supports, experience from domestic and foreign organizations, individual and research Institutes, Universities in field of water resources management in HCMC.

Conclusion

HCMC environmental management strategies up to the year 2010, approved by HCMC People's Committee in 2001, mentioned the following points as urgent issues of water resource management of the city:

- Overexploitation of groundwater which has limited reserve
- The surface water source of Sai Gon and Dong Nai rivers becomes gradually polluted
- The close relationship between surface water and ground water in water exploitation and water recharging balance.

The main objective is groundwater management is preservation of the resources through reasonable exploitation and use. To attain the objective, it is planned that the abstraction volume should be controled less than 500,000 m^3/day, which can minimize the bad impacts on ground water such as:

- Ground water contamination
- Salt destruction
- Drawdown of ground water level
- Land subsidence

Now the groundwater abstraction rate met the sustainable groundwater level so it is the time for both technical and managerial options taken. The appropriate groundwater resources law should be established for easy management.

To achieve sustainable groundwater management, it should be involved the roles of HCMC People's committee, responsible state organizations, institutes/university, industries and public community.

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Groundwater Resource Management in Osaka

Yatsuka Kataoka

1. Background of the Study Area

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 km^2 and was home to about 2.6 million people in 2002.[1] Annual precipitation ranges from 950–1,300 mm.

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 m, which consists of layers of clay and silt (GEC 1994).

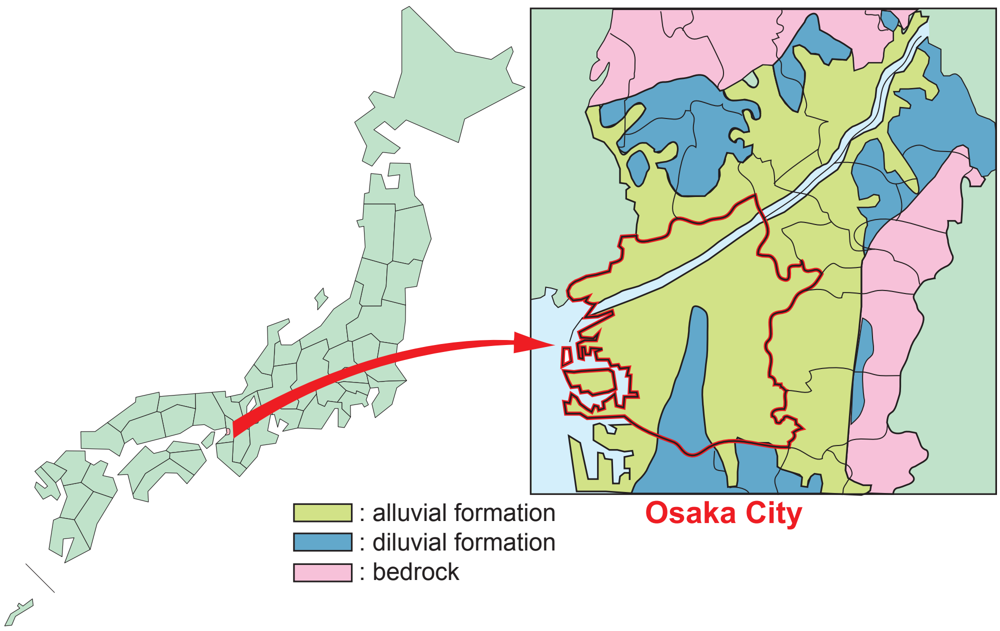

Figure 1. Location of Osaka and its Geological Characteristics

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]

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

2. Groundwater Use and its Associated Problems

2-1. Groundwater Use

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 million m^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 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% 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 million m^3 in 1953 and reached its maximum in 1962 at about 123 million m^3/yr, when 82% 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%), followed by the paper and pulp industry (21%) and the chemical industry (18%).[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).

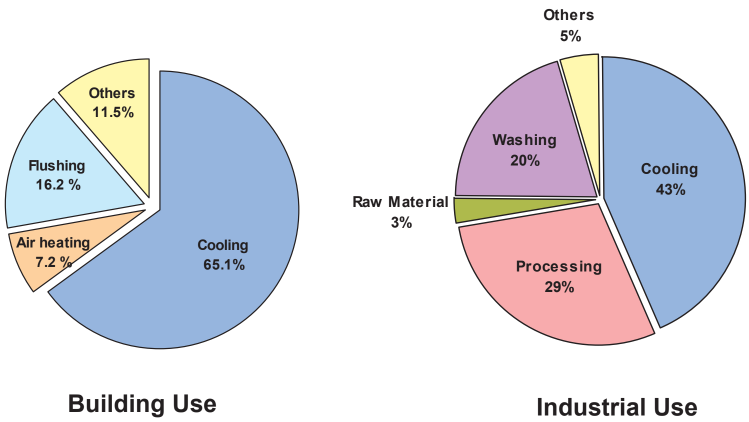

Figure 2. Groundwater Use in Osaka by Type of Use, 1962
Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1972

2-2. Problems Caused by Excessine Abstraction

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.

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 (figure 3). 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

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).

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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.

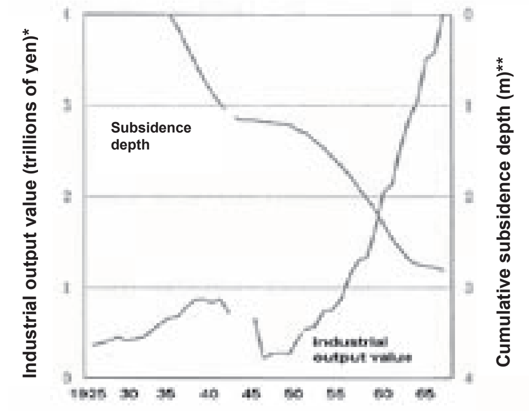

Figure 3. Land subsidence and industrial output value in Osaka

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

**In 1965 prices. **At Nishi-4 (Torishima, Konohana-ku).*

3. Policy Responses

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.

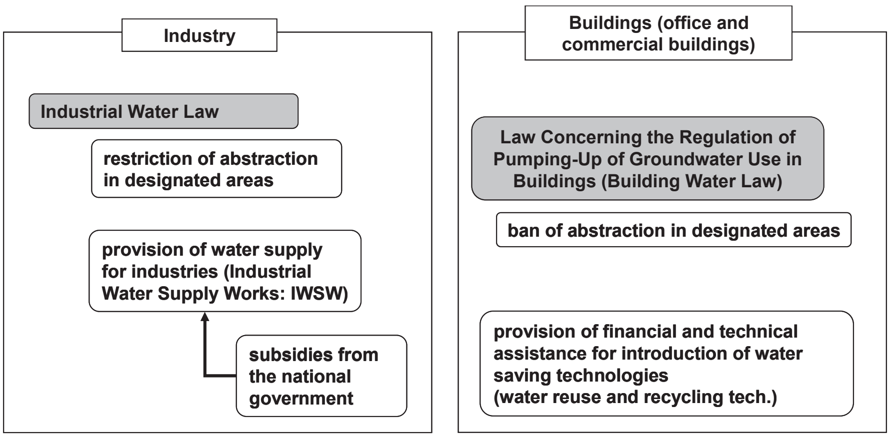

Figure 4. Outline of the Types of Groundwater Management in Osaka

3-1. 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.

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.

3-2. Construction of Industrial Water Supply Works to Provide an Alternate Water Supply to Replace Groundwater

As mentioned above, provision of alternative water sources by the 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 5). 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).

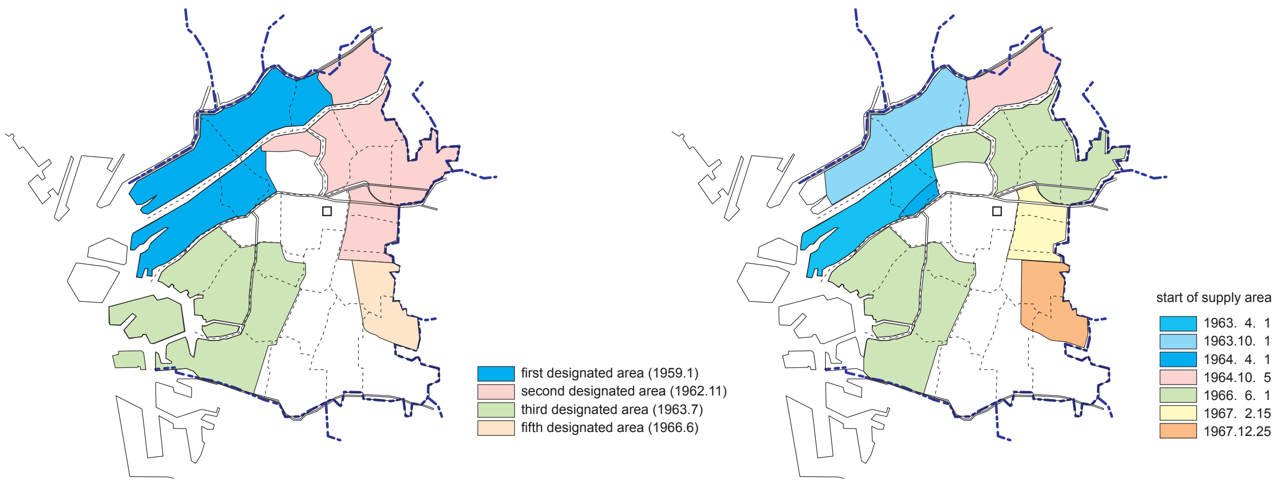

Figure 5. Areas Designated under the Industrial Water Law and Provision of Industrial Water supply works

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

The tariff of IWSW in Osaka 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].

3-3. 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.

4. Effectiveness of the Intensive Measures to Manage Groundwater

4-1. Gaining control of the dropping water table and land subsidence

As figure 6 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.

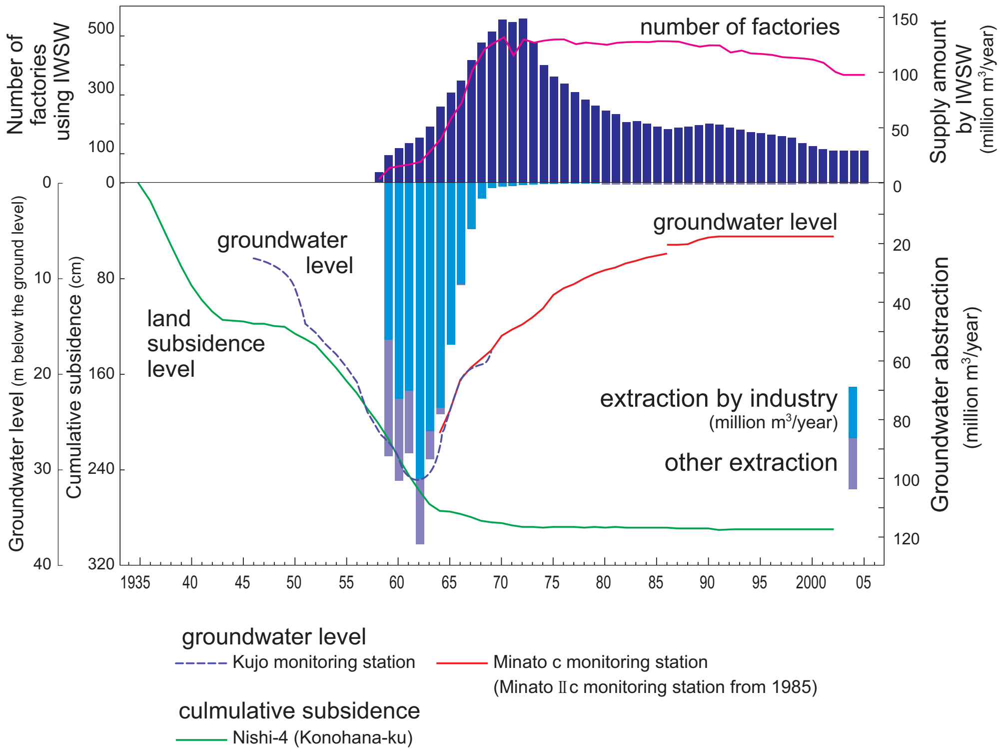

Figure 6. The Shift from Groundwater to Industrial Water Works for Water Supply in Osaka

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

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).

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.

4-2. 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 (figure 7), 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.

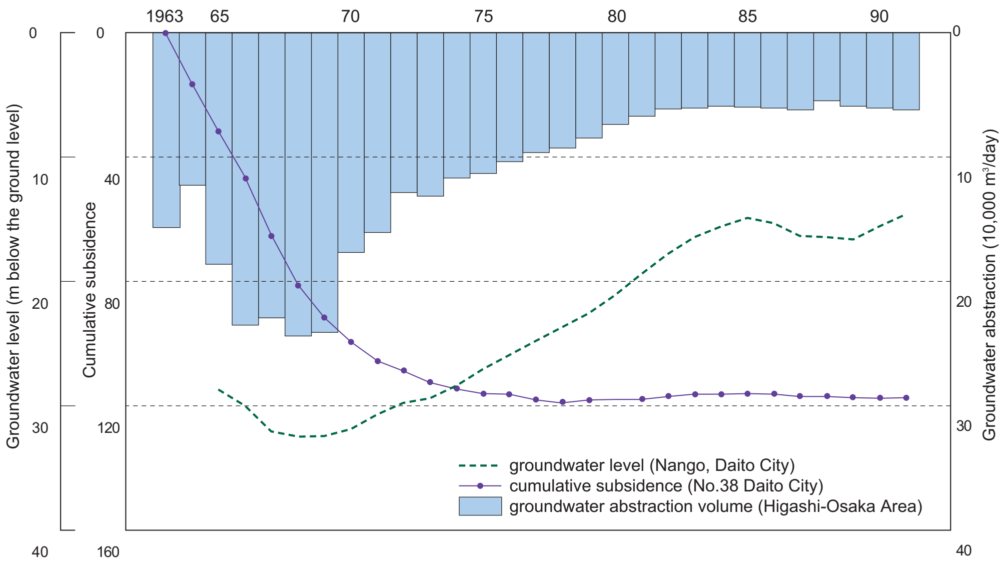

Figure 7. Cumulative Subsidence Depth and Drop in the Water Table in Higashi-Osaka

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

4-3. 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

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.

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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.

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]

Osaka also experienced a sharp increase in water recycling and reuse in 1970. The recycling rate was approximately 10% in 1958 increased to about 50% in 1970 and 90% in 2000. 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.

5. 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.

5-1. 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.

5-2. Decrease in Demand for Water from Industrial Water Supply Works

Figure 6 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

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.

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 6 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). The IWSW capacity utilization rate is now only 50 percent, and the rate would be less than 40 percent if it were based on the average supply amount,. 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.

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 8. 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.

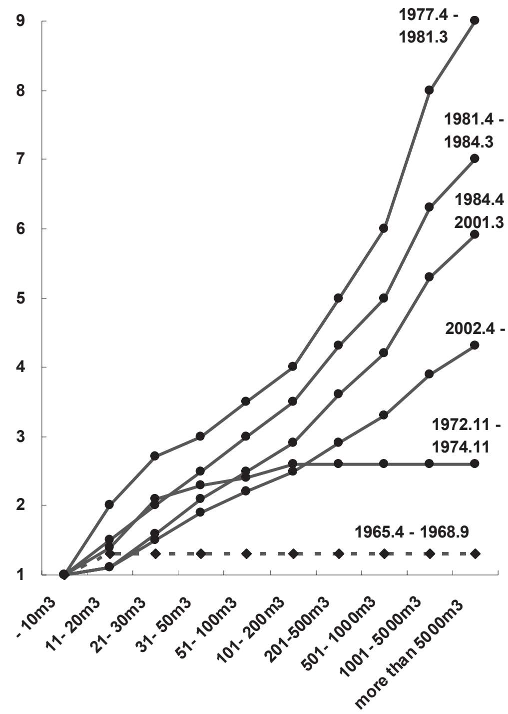

Figure 8. Progressive Rate of Sewage Charges in Osaka

Sources: Takahashi 1992.

5-3. 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.

6. 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. However, encouragement of water conservation practices in the industrial sector is not well incorporated in groundwater management in Asian cities, 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.

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