a final report of Research on Sustainable Water Management Policy

Sustainable Groundwater Management in Asian Cities

Freshwater Resources Management Project
Institute for Global Environmental Strategies

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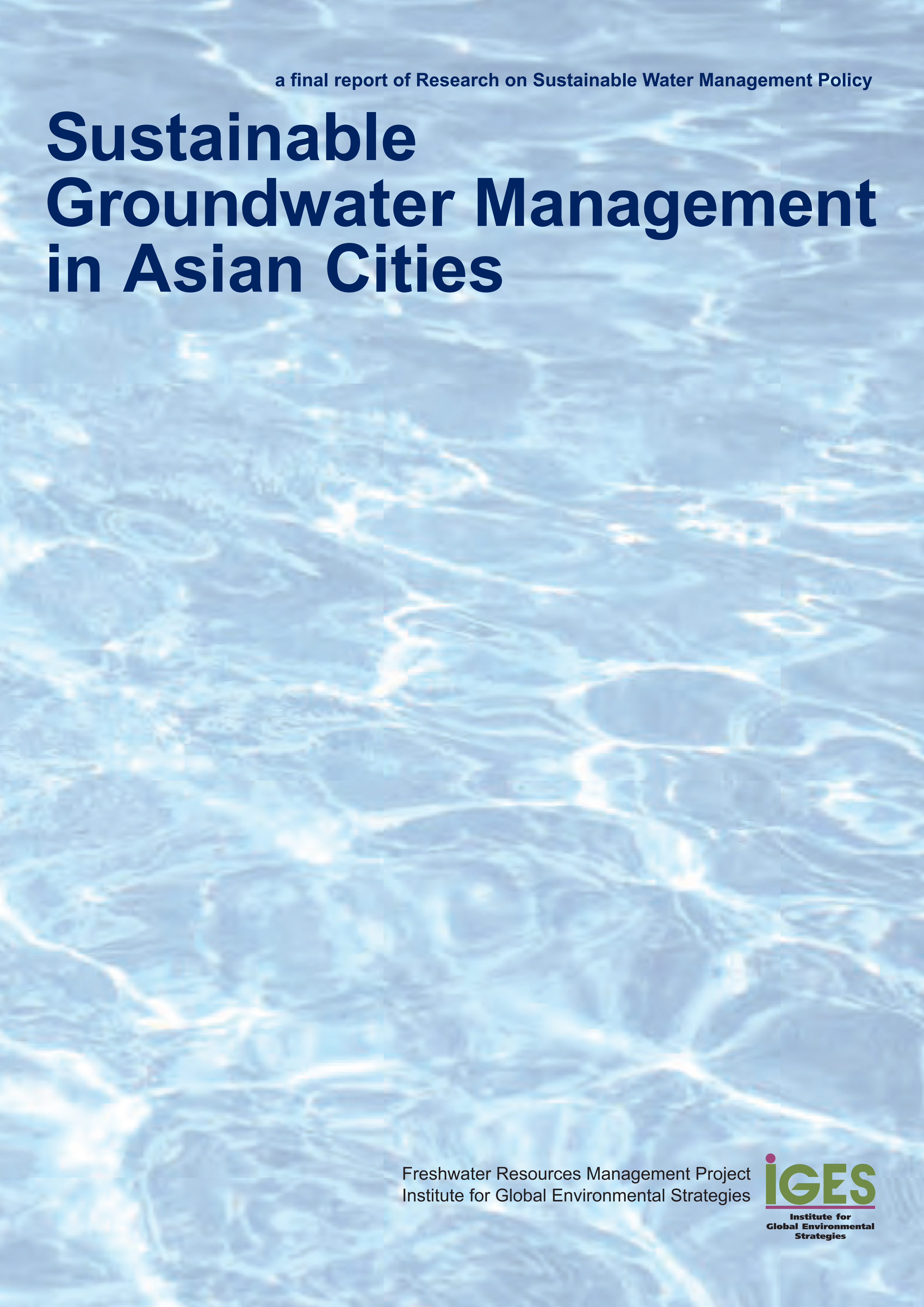

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Whilst considerable care has been taken to ensure the accuracy of the Report, the Freshwater Resources Management Project of IGES would be pleased to hear of any errors or omissions, together with the source of the information.

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Preface

Asian cities have faced problems caused by rapid urbanization for decades. While urbanization can bring economic development to the cities, it also produces decrease of natural resources or environmental deterioration. From the perspective of fresh water related issues, Asian cities are suffering from scarcity of water resources and water degradation.

Under these circumstances, groundwater has played an important role in the Asian cities. Groundwater has been used for domestic, industrial and agricultural purposes as a reliable resource in terms of quantity and quality. However, groundwater is also now under severe stress caused by excessive abstraction and contamination in the course of socio-economic development in the city. Problems such as water table depletion, land subsidence, seawater intrusion, and water degradation are emerging due to over-exploitation and contamination of water. Many efforts have already been made in order to address these groundwater related issues. Although some results were realized, their scope was limited and effects lasted for short time.

A research project, the Freshwater Resources Management Project at the Institute for Global Environmental Strategies (IGES), led by Professor Ohgaki launched a policy research, “Sustainable Water Resource Management Policy (SWMP)” in view of this situation in 2004, with the cooperation of research partners in the following case study cities, namely Tianjin (China), Bandung (Indonesia), Colombo and Kandy (Sri Lanka), Bangkok (Thailand), and Ho Chi Minh City (Vietnam). The objective of this research is to formulate policy recommendations for sustainable groundwater management in Asian cities affecting both broad amplitude and persisting time period.

This report entitled “Sustainable Groundwater Management in Asian Cities” is the final research report summarizing results of the past three years. It consists of mainly three chapters, Chapter 1 “Comparative Study of Groundwater Management”, Chapter 2 “Changes in Groundwater Management to Enhance Sustainability of Water Resources in Asian Cities”, and Chapter 3 “Summary of Case Studies”. Chapter 1 presents a summary of comparative analysis of the status of groundwater resources, existing policy measures and future challenges of six case study cities in addition to Tokyo and Osaka as reference cases. Chapter 2 explains in detail policy recommendation for sustainable groundwater management in Asian cities which was the main theme of the three-year research. Chapter 3 introduces the compilation of the summary reports from each SWMP case study city. Each summary report includes background information, status of water resources, issues on groundwater management, issues on alternative water resources for groundwater and proposed policy options in each case study city.

Finally, I would like to extend my deepest appreciation for 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 contribute to sustainable development in Asian cities.

March 2007

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

ADA	Agricultural Development Authority, Sri Lanka
ADB	Asian Development Bank
AWLR	Automatic Water Table Recorder
BOD	Biological Oxygen Demand
CEA	Central Environmental Authority, Sri Lanka
COD	Chemical Oxygen Demand
CP	Cleaner Production
DARD	Department of Agriculture and Rural Development, Viet Nam
DGR	Department of Groundwater Resources, Thailand
DI	Department of Industry, Vietnam
DIW	Department of Industrial Works, Thailand
DONRE	Department of Natural Resource and Environment, Vietnam
DOSTE	Department of Science, Technology and Environment, Vietnam
DS	Divisional Secretariat, Sri Lanka
DTPW	Department of Transportation and Public Works, Viet Nam
EC	Electric Conductivity
EIA	Environmental Impact Assessment
EPZ	Export-Processing Zones
GDF	Groundwater Development Fund
GDP	Gross Domestic Product
GPP	Gross Provincial Product
GPS	Global Positioning System
HCMC	Ho Chi Minh City
HEPA	Ho Chi Minh Environment Protection Agency, Vietnam
IEAT	Industrial Estate Authority of Thailand, Thailand
IP	Industrial Park
IWMI	International Water Management Institute, Sri Lanka
IWSW	Industrial Water Supply Works
IWTI	Industrial Water Technology Institute, Thailand
JICA	Japan International Cooperation Agency, Japan
MARD	Ministry of Agriculture and Rural Development, Viet Nam
MC	Ministry of Construction, China
MI	Ministry of Industry, Thailand
MLR	Ministry of Land and Resources, China
MONRE	Ministry of Natural Resources and Environment, Thailand/Viet Nam
MWA	Metropolitan Water Works Authority, Thailand
MWR	Ministry of Water Resources, China
NCWR	National Water Resources Council
NEB	National Environment Board, Thailand
NEDO	New Energy and Industrial Technology Development Organization, Japan
NEPA	National Environment Protection Agency, China
NGO	Non-governmental Organisation
NRW	Non-revenue Water, Sri Lanka
NWS & DB	National Water Supply and Drainage Board, Sri Lanka
OMWRM	Office of Minerals and Water Resources Management
PC	People’s Committee, Viet Nam
PDAM	Regional Water Company, Indonesia
PWA	Provincial Waterworks Authority, Thailand
RBO	River Basin Organization
RGDP	Regional Gross Domestic Product
RID	Royal Irrigation Department, Thailand
RTSD	Royal Thai Survey Department
RW	Reclaimed Water
RWH	Rain Water Harvesting
SAWASCO	Saigon Water Supply Company, Vietnam
SDPC	State Development Planning Commission, China
SEA	Strategic Environmental Assessment
SWOP	Strength – Weakness – Opportunity – Potentials
TEDA	Technologic-Economic Development Area, China
UNEP	United Nations Environment Programme
UNICEF	United Nations Eductional, Scientific and Cultural Organisation
VOCs	Volatile Organic Compounds
WHO	World Health Organisation
WRB	Water Resources Board, Sri Lanka
WSE	Water Supply Enterprise, Indonesia
WTP	Water Treatment Plant

[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

[Units]

mm	millimeter
cm	centimeter
m	meter
m^2	square meter
m^3	cubic meter
km	kilometer
km^2	square kilometer
km^3	cubic kilometer
°C	degree Celsius
%	percent
ml	mili liter
l	liter
mg/l	milligram per liter
MPN	most probable number
CFU	colony forming unit

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 (10,315 km^2): 7 Provinces namely, Bangkok, Nonthaburi, Samut Prakan, Pathumthani, Samut, Sakhon, Nakhon Pathom, and Ayutthaya
Bangkok Metropolitan Region (2,844 km^2): 3 provinces namely, Bangkok, Nonthaburi, and Samut Prakan
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 (1,894 km^2): Osaka Prefecture
Osaka City (222 km^2): Osaka city
Tokyo (1,781 km^2): Tokyo (Tokyo 23 Wards and Tama Area)
Tokyo 23 Wards (621 km^2): Tokyo 23 Wards

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

The report uses the local currency unit for each case study country. The currency rate of each unit in US dollar is as following

[Currency Equivalents]
1 JPY (Japanese Yen) = 0.008481 USD (US Dollar)
1 THB (Thai Baht) = 0.03116 USD (US Dollar)
1 IDR (Indonesian Rupiah) = 0.0001098 USD (US Dollar)
1 VND (Vietnamese Dong) = 0.00006486 USD (US Dollar)
1 CNY (Chinese Yuan Renminbi) = 0.12952 USD (US Dollar)
1 LKR (Sri Lanka Rupee) = 0.009208 USD (US Dollar) as of March 2007
1JPY (Japanese Yen) = 0.003293 US Dollar as of March 1972

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.

INTRODUCTION

Groundwater is a reliable source of water for drinking and production both in quantity and quality if the resource is properly managed. However, this resource is now under stress in some Asian cities because of unregulated and excessive abstraction occurring alongside socio-economic development. Problems such as water table drawdown, decreasing well yield, land subsidence, and salinity intrusion have emerged as the results of overexploitation of groundwater. Groundwater quality degradation caused by coliform and heavy metals has also been observed. Such problems may incur socio-economic losses and disturb the development of the cities. These problems are either irreversible in nature or require extended periods to abate, and therefore it is better to take actions to mitigate or prevent them.

However, information on groundwater, such as actual groundwater use and management practices, is currently very limited. This constitutes a barrier to sound discussion on what action is necessary for sustainable use of groundwater, which is to say, what actions are necessary to conserve this precious resource while taking full advantage of it for the development of Asian cities. Sustainable use of groundwater is also important in the pursuit of integrated water resource management.

With the significance of sound groundwater management in Asian cities in mind, the Freshwater Resources Management Project of the Institute for Global Environmental Strategies placed its research focus on groundwater management, particularly in the urban and peri-urban areas of Asian cities. The research entitled “Sustainable Water Resource Management Policy in Asia” (SWMP) aimed to show the state of groundwater and its management in Asian cities.

The state of water resources and how they are used is closely related to the local social, economic, and environmental conditions and, therefore, there is no panacea for the current groundwater issues. Keeping this in mind, we focused on case studies as a core research element of the SWMP research. The case studies were conducted in Bangkok, Thailand; Ho Chi Minh City, Viet Nam; Bandung, Indonesia; and Tianjin, China. Colombo and Kandy in Sri Lanka, and Osaka and Tokyo in Japan were also studied. Based on the case studies, and targeted at those involved in groundwater management, i.e. policy makers, we conducted a comparative study and recommended necessary actions for the sustainable use of groundwater. Throughout the three-year research we held stakeholder meetings in the respective case study cities and discussed our research findings with local stakeholders.

This report entitled “Sustainable Groundwater Management in Asian Cities for Sustainability” contains the main outputs of the three-year research. This report consists of three main chapters. The first chapter comprises highlights of the comparative analysis, the second chapter presents recommendations for sustainable groundwater management based on our research findings, and the final chapter contains summaries of the respective case studies. This report shows that groundwater is still used as an important resource in social and economic activities in cities, even while it becomes increasingly stressed. Considering that current groundwater management practices are not well integrated with management of other water resources and other policy areas such as land use, we recommended that groundwater should be integrated with these other water management policies and other policy areas. In addition, we highlighted that promotion of the rational use of water, especially in the industrial sector in which water demands are increasing, is essential for the sustainable future of water resources, including groundwater.

CHAPTER 1
CHAPTER 2
CHAPTER 3

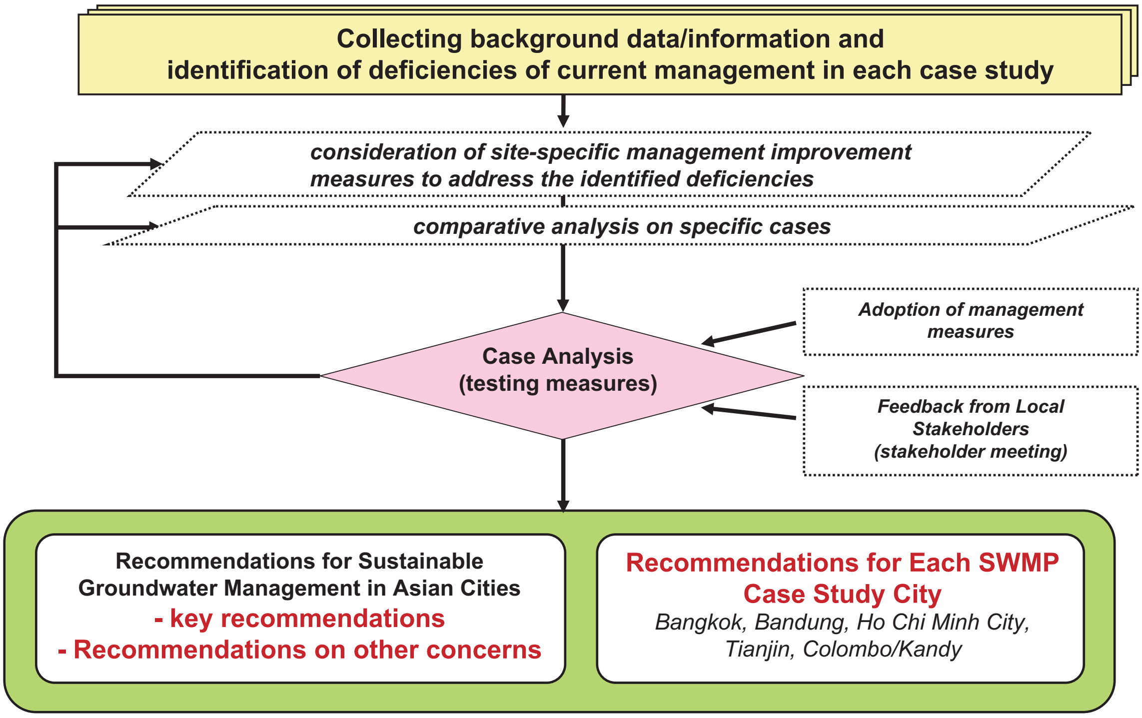


Figure 1. Outline of the Reserch

CHAPTER 1

COMPARATIVE STUDY OF GROUNDWATER MANAGEMENT

- based on the case studies in Asian cities -

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

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

1. Background to the Case Study Cities

1.1 Socioeconomic Condition

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

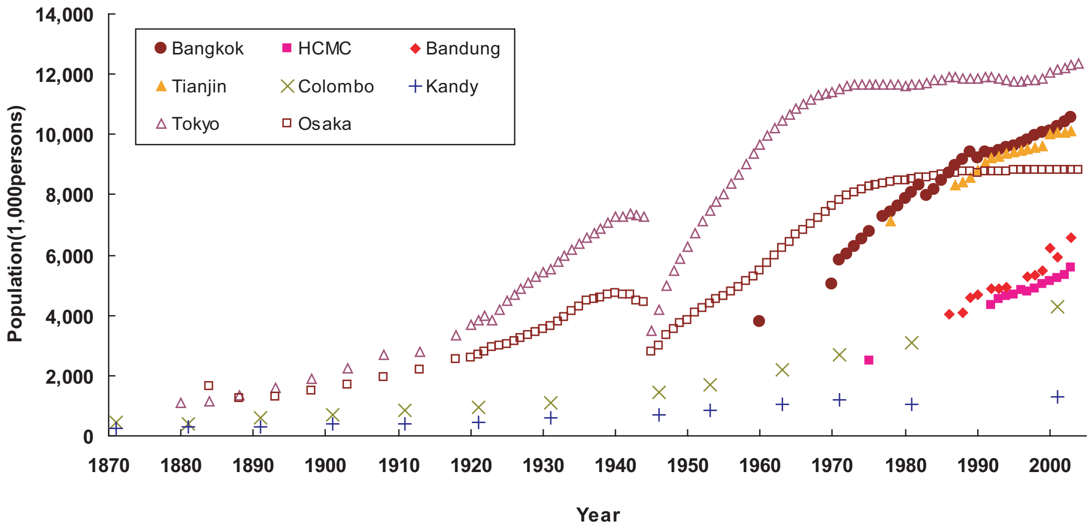


Figure 1. Population Increase since 1870 in Case Study Cities

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

Table 1. Study Area and Population Density

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

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

Table 2. Economic Status of Case Study Cities

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

1.2 Climatic Condition

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

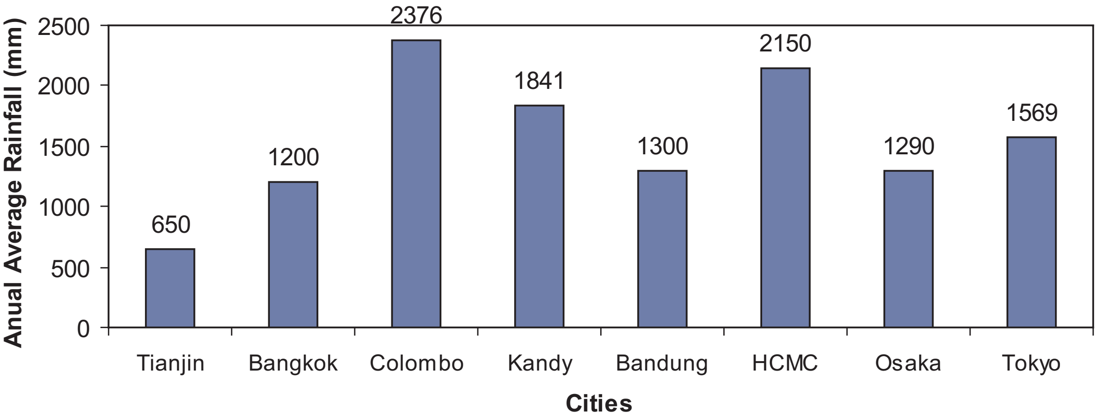


Figure 2. Annual Average Rainfall

Table 3. Average Maximum and Minimum Temperature

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

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

2. *The State of Groundwater Resources*

2.1 Status of Groundwater Resources

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

2.2 Groundwater Use

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

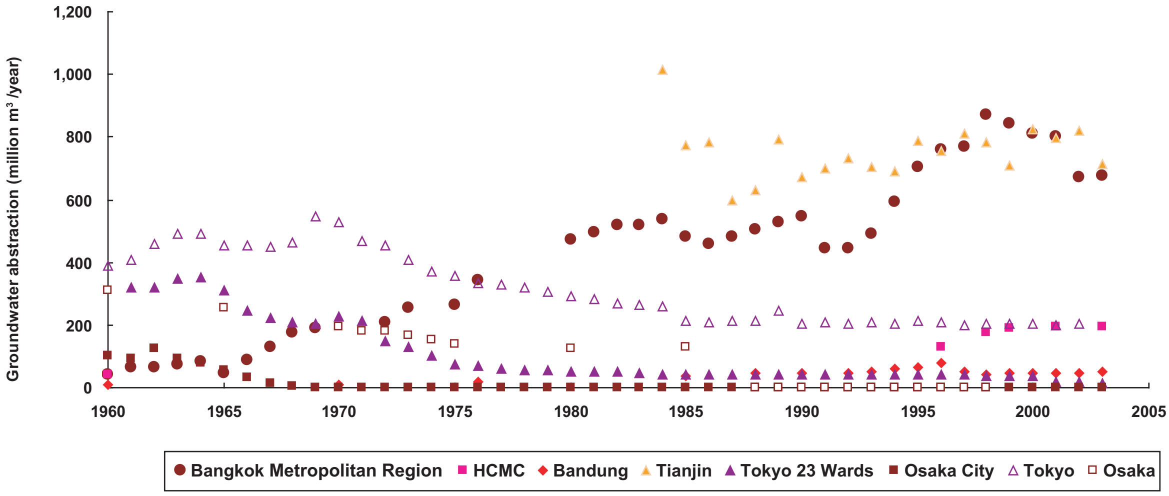


Figure 3. Chronological Groundwater Use in Case Study Cities (except Sri Lanakan Cities)

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

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

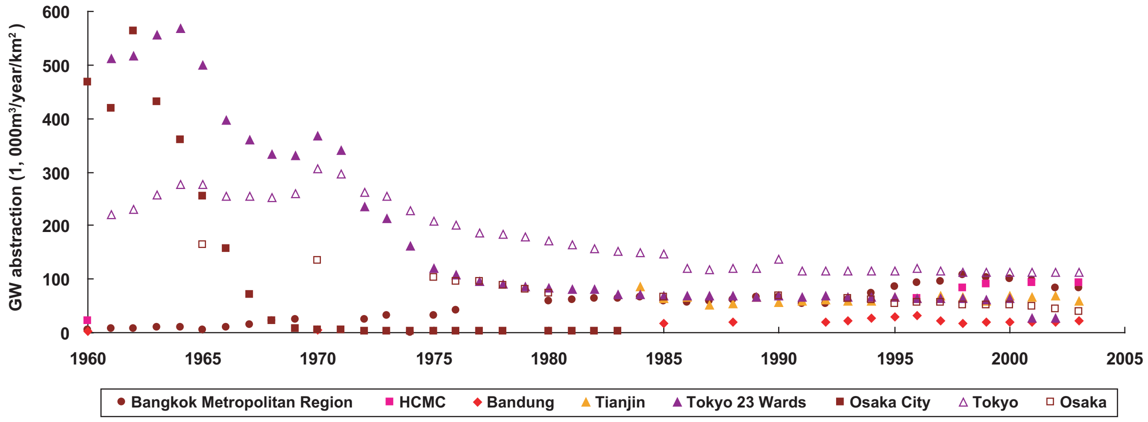


Figure 4. Chronological Groundwater Use on Area per Square Kilometer in Case Study Cities (except Sri Lanakan Cities)

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

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

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

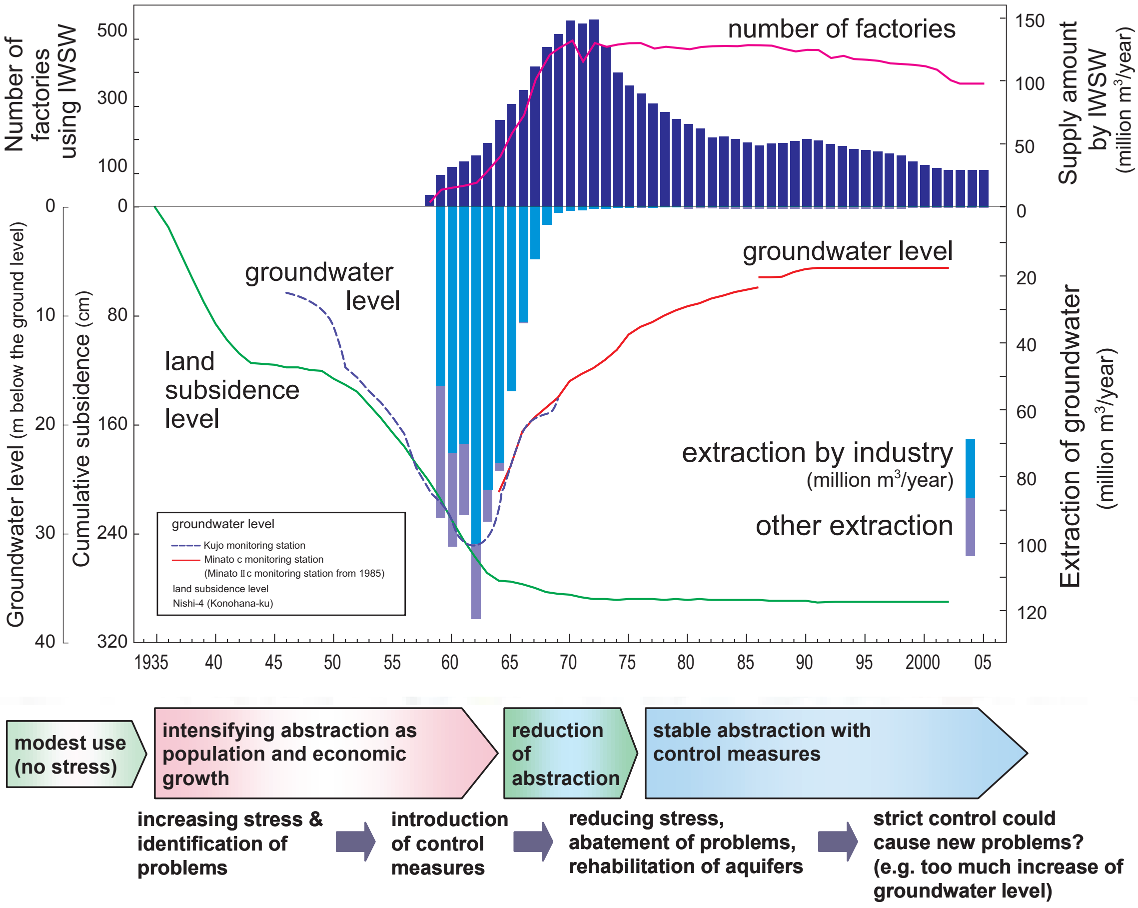
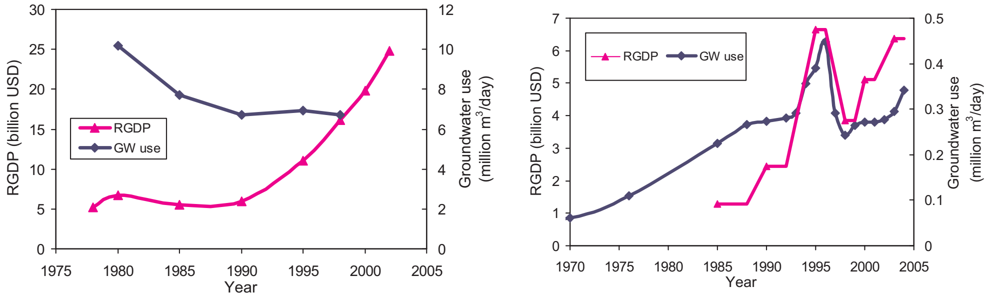


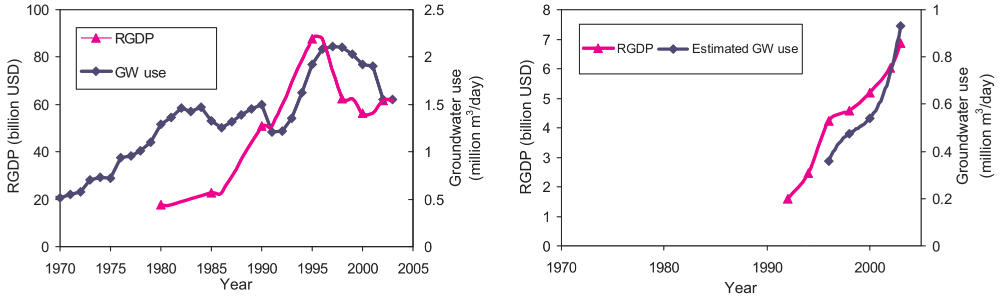
Figure 5. General Path of Groundwater Use (Case of Osaka City)

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



(a) Tianjin

(b) Bandung



(c) Bangkok

(d) HCMC

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

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

Table 4. Effects of Intensive Use of Groundwater

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

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

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

2.3 Groundwater Quality

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

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

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

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

*** Data in 2004*

Tri-CE: Trichloreethylene, Tetra-CE: Tetrachloroethylene

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

2.4 Problems Associated with Groundwater

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

Table 6. Water Stress

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

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

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

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

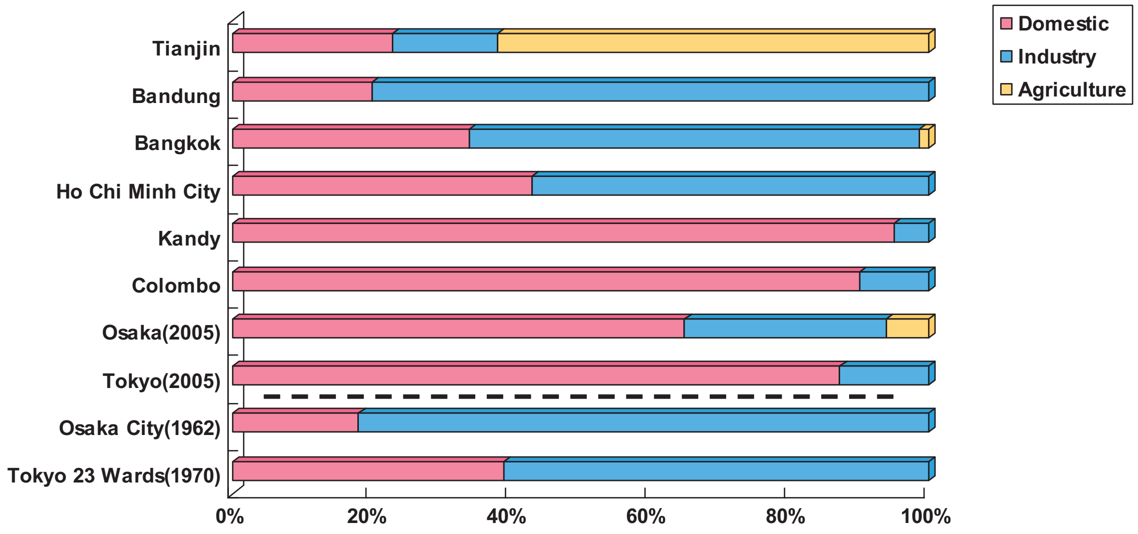


Figure 7. Beneficial Use of Groundwater

2.5 Groundwater Right

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

3. The Management of Groundwater Resources

3.1 Summary

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

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

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

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

3.2 Characteristics of Groundwater Management in Case Study Cities

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

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

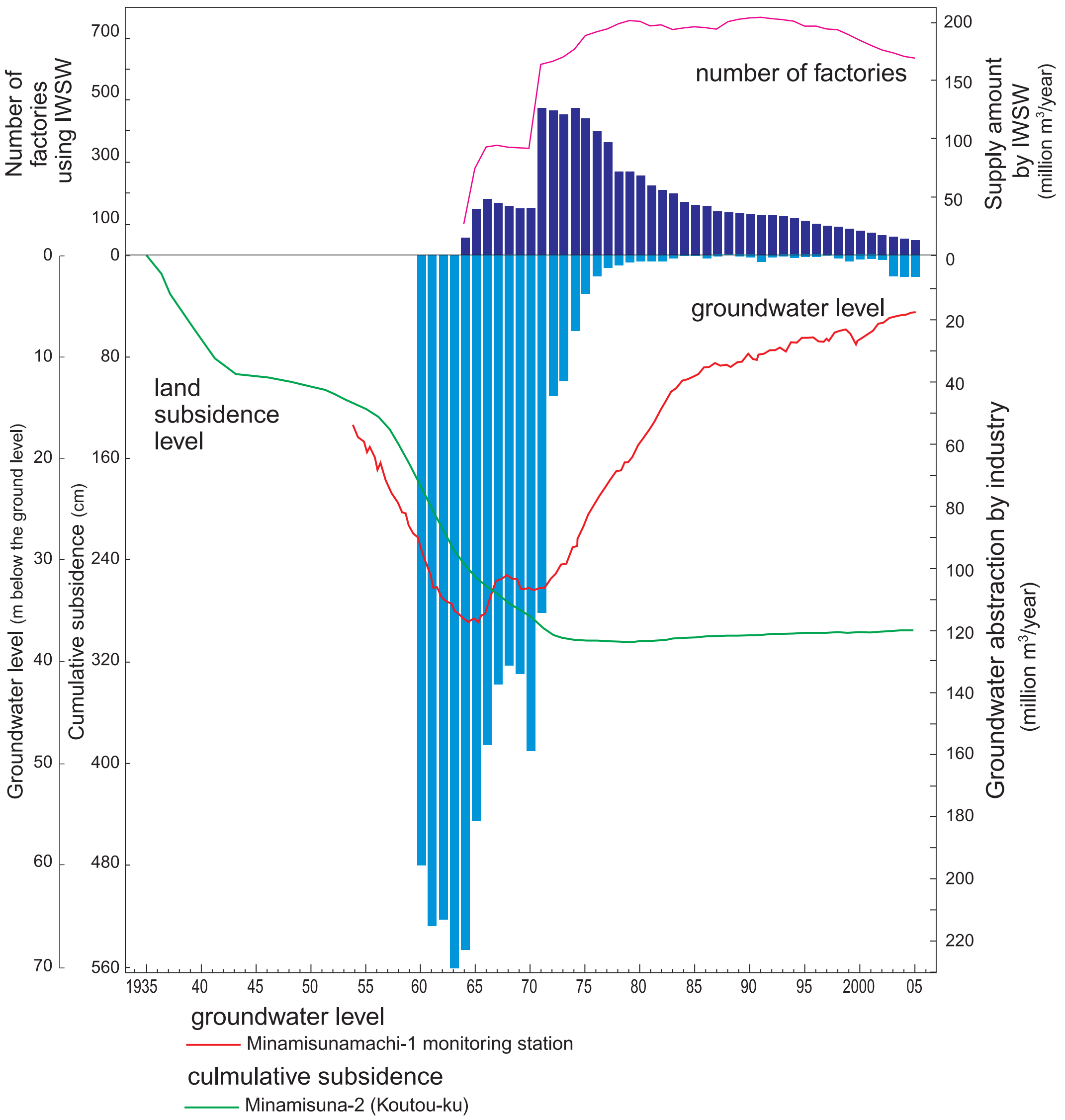


Figure 8. Shift from Groundwater to Industrial Water Works for Water Supply (Case of Eight Wards in Tokyo)

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

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

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

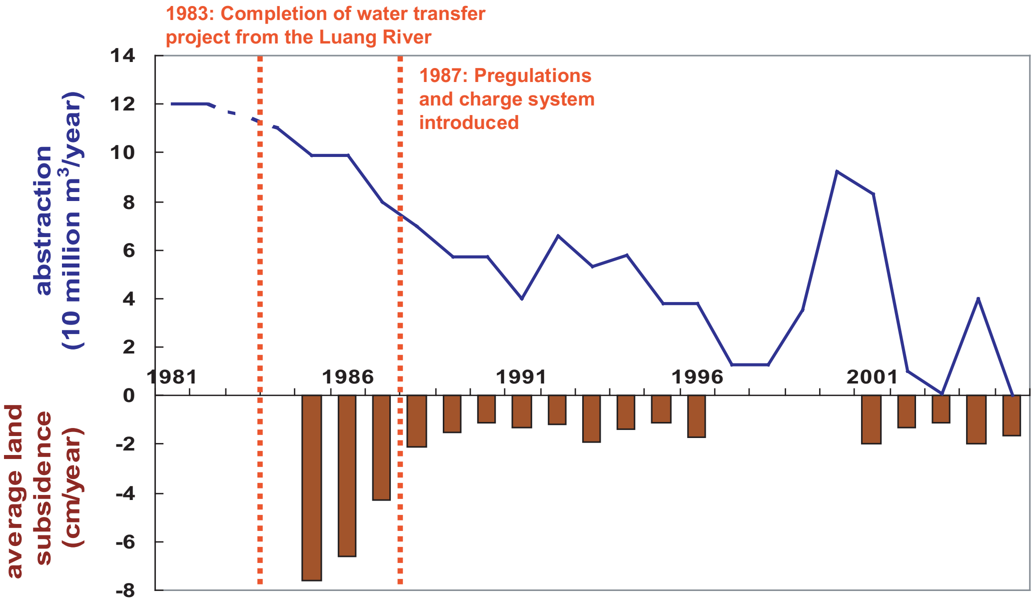


Figure 9. Groundwater Abstraction and Land Subsidence in Urban District in Tianjin

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

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

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

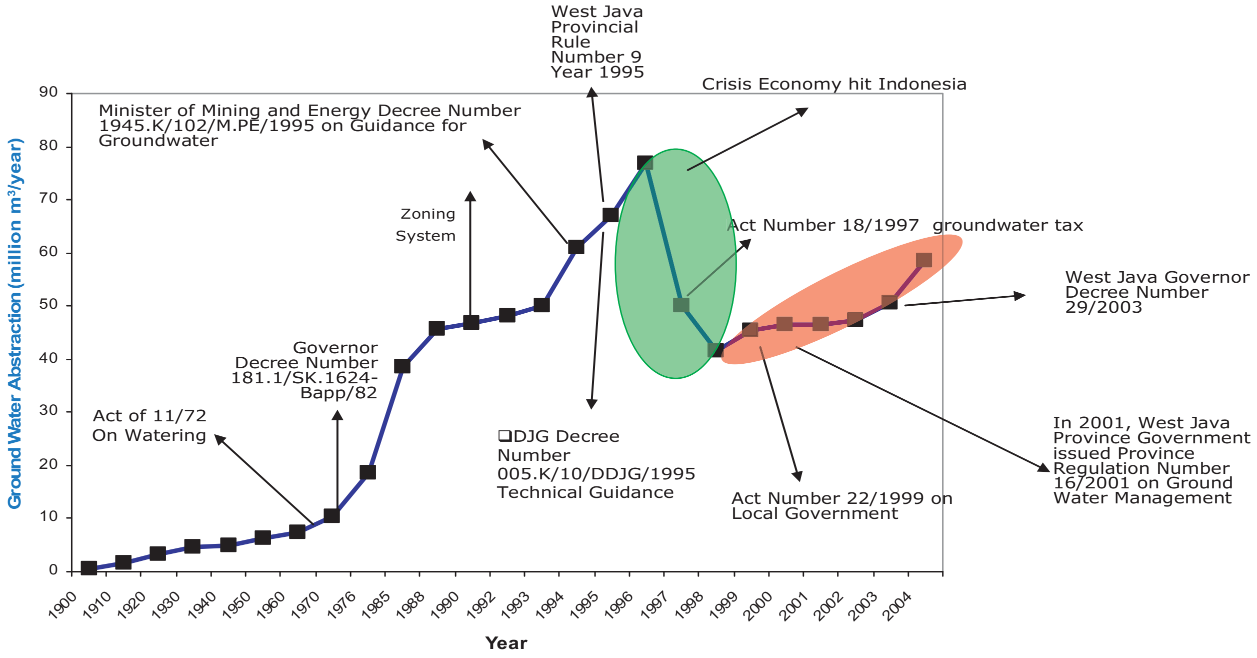


Figure 10. Deep Groundwater Use and Measures Taken in Bandung

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

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

3.3 Review of Management Measures

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

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

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

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

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

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

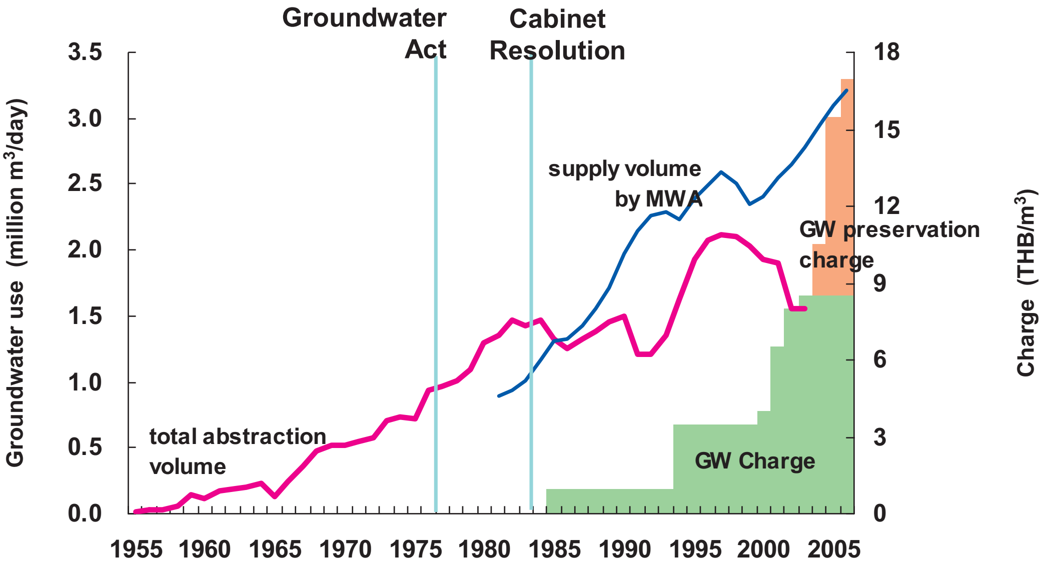


Figure 11. Groundwater Use Charge and Groundwater Abstraction in Bangkok

Note: GW means Groundwater

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

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

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

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

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

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

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

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

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

Table 8. The Status of Groundwater Quality Monitoring

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

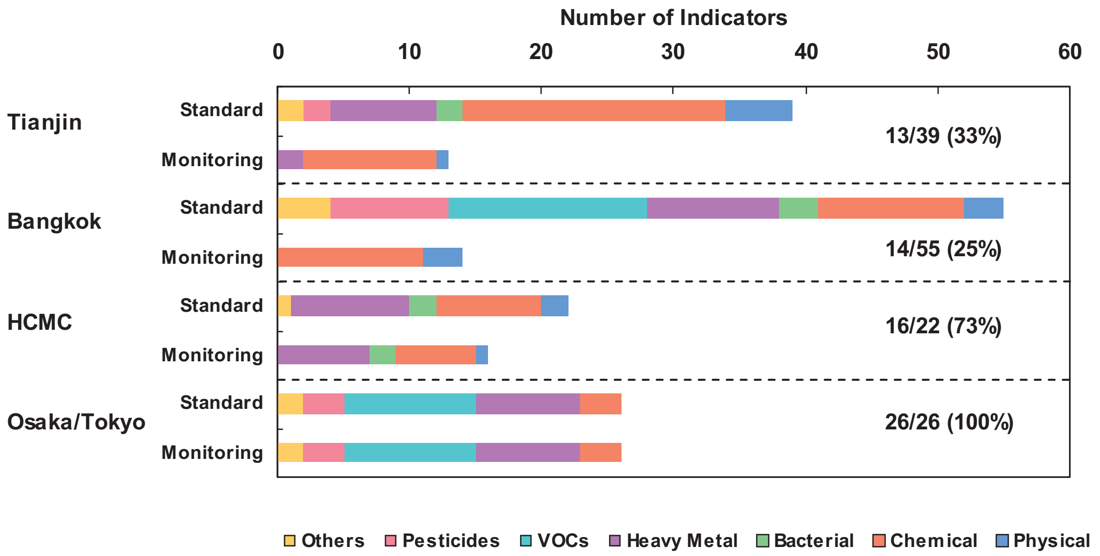


Figure 12. Number of Indicators Tested at the Regular Groundwater Quality Monitoring and Designed in the Groundwater Quality Standard

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

4. Conclusion

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

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

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

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

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

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

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

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

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

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CHAPTER 2

CHANGES IN GROUNDWATER MANAGEMENT TO ENHANCE SUSTAINABILITY OF WATER RESOURCES IN ASIAN CITIES

- Recommendations from SWMP -

As one of the outputs of the three-year research, we formulated recommendations for making groundwater management in Asian cities better in order to enhance sustainability of water resources. The recommendations are divided into two types: Recommendations for Sustainable Groundwater Management in Asian Cities and Recommendations for Each SWMP Case Study City.

The first type of recommendations addresses the common concerns on groundwater management shared by many Asian cities. The recommendations are further divided into two categories, namely, "key recommendations" and "recommendations on other concerns". The key recommendations are intended to address the common and critical issues of groundwater management identified through the research. The second type of recommendations deals with other concerns on groundwater management which were identified at the series of dialogues with relevant stakeholders in these case study cities. When these recommendations are put into practice, they should be interpreted and optimised in accordance with local contexts, such as the local hydro-geological, social, economic and cultural conditions.

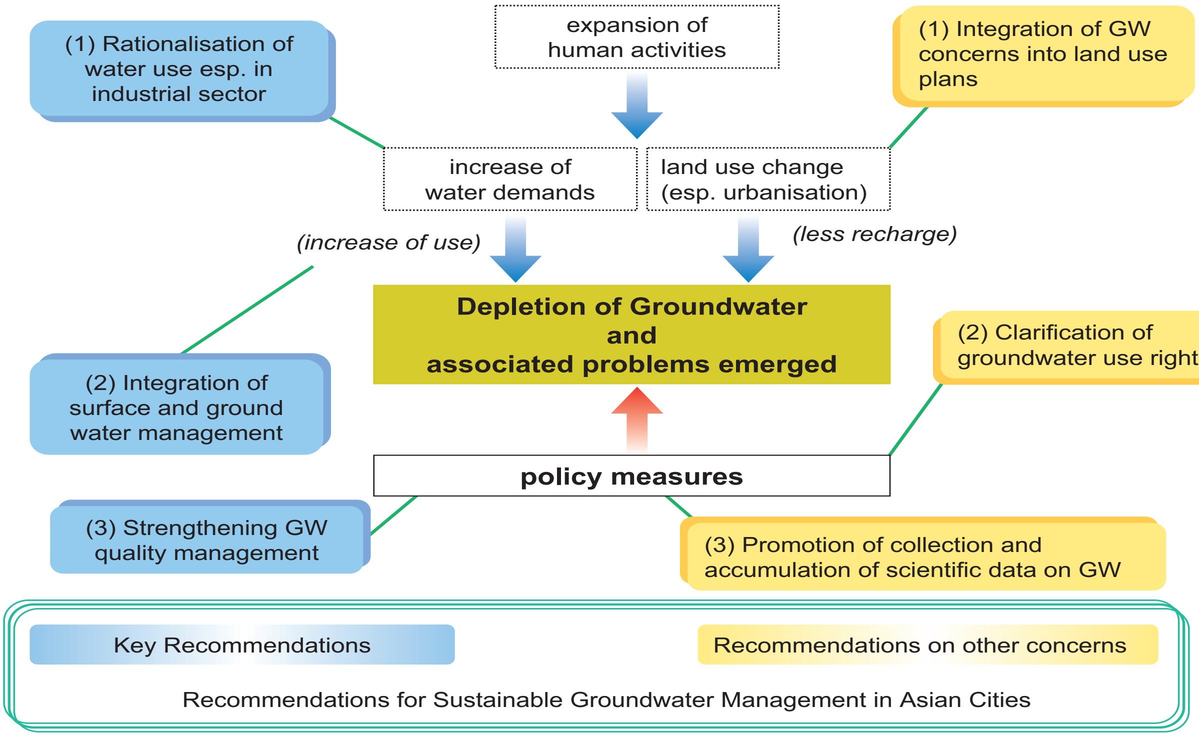

Figure 1. Categorization of Proposed Recommendations

1. Recommendations for Sustainable Groundwater Management in Asian Cities

1.1. Key Recommendations

Recommendation 1
Rationalisation of water use should be prioritised in urban water management. In particular, more governmental resources should be allocated for the promotion of rational water use by the industrial sector, which is a large user of groundwater.

As we saw in Bangkok, Bandung, and Osaka and Tokyo in the 1950s and 60s, intensive use of groundwater by the industrial sector was a major cause of depletion of the resource, which is often associated with other environment problems such as salt water intrusion and land subsidence. To mitigate such problems, governmental policy tried to limit groundwater use by the industrial sector. Industries provide an important basis for economic and social activities, and therefore it is often difficult to enforce reduction of industrial groundwater use without provision of other reliable sources of water as alternatives to groundwater.

On the other hand, providing surface water supply to act as an alternative to groundwater use is not feasible in many cases, such as in Bandung, because surface water resources available are too limited to be an alternative source of groundwater. Even if there is potential for surface water capacity, development of a new water supply infrastructure needs significant financial resources and is often associated with risk to the local environment. In such cases **priority should be given to measures to promote rational use, such as water reclamation and reuse and conjunctive use of different water sources including surface, ground and reclaimed water.**

In promoting the rationalisation of water use in industries, the following elements should be addressed.

i. **Coordination with ministries and agencies engaged in different aspects of industrial water use should be facilitated.** Water use by the industrial sector, especially in industrial parks, is often under the jurisdiction of industrial ministries. Promotion of water recycling is also often conducted by industrial ministries. On the other hand, public water supply is a matter for water-related agencies and conservation of water resources may come under the remit of environmental ministries. Coordinating between different organisations' policies also helps minimise transaction costs in implementation of relevant policy measures.

ii. **Economic incentives/disincentives to promote rational use of water should be provided to change water use practices in industries.** Such economic instruments include (i) increase of water charges including a groundwater user charge, (ii) introduction of a wastewater discharge fee, and (iii) financial support during the initial stages of introduction of relevant technologies.

iii. **Stringent enforcement of water quality standards would help to motivate the rational use of water.** Stringent water quality standards and/or strengthened enforcement of such standards may increase the cost of wastewater treatment. Industries could be persuaded to use water rationally in order to avoid the costs of introducing upgraded water treatment systems to meet more stringent standards. Efforts to minimise freshwater supplies would also be undertaken to increase efficiency of wastewater treatment.

iv. **Technical guidelines and quality standards for reclaimed water use and conjunctive use ought to be prepared by governments for different types of users and intended purposes.** Proper guidelines and quality standards are crucial in order to minimise potential risks to human health, goods, and also the environment. The quality of water required differs between beneficial uses and intended purposes. Therefore, different guidelines and standards should be set.

v. **Awareness on the part of the industrial sector of potential benefits of water reclamation and reuse should be promoted** through technical training and water recycling programmes as we saw in the Bandung case study. Such benefits include; reliable quantity and quality of reclaimed water, economic benefits brought by reduction of the cost of freshwater supplies as well as wastewater treatment, and diminished environmental impacts.

Recommendation 2

Management policy on groundwater should be integrated with that on surface water and other sources of water. This integration will enable more efficient and sustainable use of available water sources.

Some successes in groundwater control in case studies show that the provision of surface water as an alternative to groundwater is a very important factor in the success of groundwater use controls. Examples include the inter-basin transfer projects in Tianjin, extension of piped water supply in Bangkok, and Industrial Water Supply Works in Japan. As the successes show, groundwater management is very closely linked with management policy on other water sources. However, even in the success cases, groundwater is often managed independently or there are discrepancies in the views water use as a whole. To promote efficient use of the limited water resources, it is necessary to integrate groundwater management policy with management policy of other water sources. To promote integration, the following aspects should be considered.

i. **An integrated water plan needs to be formulated for effective management.** If such an integrated plan exists, the common goals of water management will be clarified and shared among relevant stakeholders. Practical measures to address discrepancies among current management measures on different water sources should be included in such a plan.

ii. **Organisational arrangements should be reinforced by clarifying the responsibilities of each organisation and setting mechanisms for policy coordination for different water sources.** Proper organisational arrangements could promote integrative planning and management. Such integrative approaches not only optimise management costs, but are also very useful in minimising risks by diversifying sources of water.

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

Recommendation 3

Groundwater quality management should be strengthened to secure the safe use of the groundwater.

Groundwater is still used as an important resource for drinking purposes in Asian cities. In some cities people can drink groundwater without treatment if it is not artificially polluted. We observed that our case study cities suffer from specific pollution, such as naturally occurring pollutants (e.g., fluorine), salinisation due to sea water intrusion, and coliform contamination caused by improperly treated domestic wastewater. Due to this contamination, groundwater can not be used for drinking without treatment.

Not only is the treatment of domestic and industrial wastewater and hazardous solid waste very poor, but also fertiliser and pesticides are used in agricultural activity in the case study cities. In addition, because rapid urbanisation and intensive agriculture may accelerate further in the future, new types of pollutants such as heavy metals, VOCs, and pesticides which have not been serious problems or monitored so far might represent future risks to groundwater.

Although there are laws and regulations on groundwater quality management which address the traditional types of groundwater pollution, the implementation of these laws and regulations is quite weak in the case study cites. In addition, groundwater quality management systems for new types of pollutants have not been established yet.

Therefore, groundwater quality management should be strengthened for the sustainable use of safe groundwater in consideration of the following points.

i. **Groundwater quality monitoring systems should be established or strengthened in order to support the active use of groundwater.** Especially, information on water quality issues relating to emerging pollutants (such as VOCs) should be collected.

ii. Based on the appropriate monitoring data on water quality and identified pollution sources, **water quality standards should be designed to fit the local conditions of water quality and policy direction.** In addition, different quality requirements for different beneficial uses should also be set up to promote the effective use of water resources.

iii. Because both the increase in contaminants and the diversity of pollutants are likely to affect Asian cities in the future due to rapid industrialisation and intensive agricultural activity, **innovative pollution controls, especially for groundwater conservation, should be implemented in order to reduce the increased risk of groundwater contamination.** Reduction of discharged wastewater through wastewater reuse/recycling which can reduce the groundwater contamination risk should be implemented as a first step. New technologies available should be fully utilised.

1.2. Recommendations on Other Concerns

Recommendation 4

Land use plans should integrate groundwater concerns to maintain sustainability of the resource.

Urbanisation 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 distorted and changed into denuded, cultivated, or paved areas. These changes often reduce the recharging capacity of groundwater, thereby increasing and accelerating surface runoff. Despite there being such a close link between land use and groundwater conservation, land use plans often fail to include concerns for groundwater conservation. In practice, the following actions should be considered.

i. **Recharging zones should be protected against uncontrolled development to maintain the recharging capacity of groundwater, and such concerns should be included in a land use plan.** Conservation of forest areas in upper stream zones may contribute to maintaining groundwater recharging capacity.

ii. Artificial recharging of aquifers is useful in maintaining the sustainability of groundwater quantity in areas where groundwater stress is very high. **In recharging groundwater, however, due consideration should be paid so as not to degrade the original quality of groundwater. Guidelines on water quality for recharging should be set, considering both the original quality and the required quality for beneficial use.**

iii. **Locations of landfill sites and industries,** especially those which use potentially hazardous materials such as chemicals/heavy metals, **should be carefully considered so as not to affect the quality of groundwater.** If groundwater is used especially for potable use, the area where recharging and water intake take place should be protected.

iv. Public awareness is a key issue to promote recharging of groundwater. **Decentralised recharging schemes in households or communities can contribute to the public awareness.** Rainwater harvesting in areas with enough precipitation is also effective for groundwater recharge. For example, installation of rainwater harvesting facilities can be mandated or encouraged in building codes as a source of water for non-potable domestic use or recharging.

Recommendation 5
Groundwater abstraction/use rights should be granted to groundwater users under government controls. These rights systems should be clarified in statutory forms in the relevant laws.

Groundwater abstraction/use rights sometimes hinder the effective planning and implementation of groundwater management especially in countries where groundwater is widely recognised as private property such as Sri Lanka and Japan. For example, there was a debate in Japan in the 1950s on whether groundwater use could be regulated by laws and regulations. As people became aware of the problem of land subsidence as a result of intensive groundwater use, government restrictions on groundwater became viable for the sake of public welfare. However, it is still difficult to impose charges on groundwater users in Japan partly because the right to use groundwater still remains private.

In the initial stage of groundwater use, there are often no regulations or control of groundwater use and therefore individual groundwater users can abstract groundwater in their private lots as much as they want until the groundwater dries up. For sustainable use of groundwater there must be rules that all groundwater users need to follow, in most cases this will be in the form of laws and regulations. Charging for groundwater use is a way to rationalise water use, but an effective charging system should be supported by clear ideas of who has the rights to abstract and use groundwater and to what extent. Groundwater use rights are very important as a basis for the introduction and implementation of measures to control use of groundwater as a common good that people shall share. Therefore, **it is better to define the abstraction/use rights in statutory form and clarify the roles of government as a sound basis for groundwater management policy planning and implementation.**

Recommendation 6
Collection and accumulation of scientific data on groundwater should be promoted as the basis for sound groundwater management.

The current scientific information on groundwater to support groundwater management is either very limited or not well accumulated. In order to overcome the situation and promote effective groundwater management, the following actions are recommended.

i. **Database systems pertaining to groundwater should be established or upgraded to share reliable information with relevant stakeholders.** Basic facts such as geological formation, groundwater level and groundwater use should be included in the database. Currently, certain amounts of data on groundwater levels are often gathered in the region, but other facts such as how groundwater exists and how much groundwater is used are poorly stored.

ii. In most cases, financial resource for data collection and accumulation are limited. To use such limited resources effectively, **collecting data on the quality and quantity of groundwater should be prioritised giving due consideration to the local situation and policy objectives of each city.** In addition to the governmental sector, universities could play a role in the collection and analysis of data and information for policy making as neutrals in Asian cities.

iii. **In order to increase financial resources to establish a database system, using part of the revenue from groundwater charges should be considered.** A new charging system introduced in Bangkok and some cities in Japan is one option.

iv. **The definitions of technical terms are very important in promoting sound discussion and common understanding of accumulated data.** Precise definitions of terms are crucial, especially in the international context. Controversial terms include safe yield and sustainable yield. The terms should be defined based on reliable scientific data relevant stakeholders can agree on.

2. Summary of Recommendations for Each Case Study City

Recommendations specifically aimed at each case study city were formulated by our research partners. Details of the recommendations are described in the respective case study summary reports in Chapter 3, but in this section there is an overview of the site-specific recommendations provided in the following table.

Table 1. Summary of Recommendations for Each Case Study City

Area of Recommendations	Bangkok	Bandung	HCMC	Tianjin	Sri Lanka
Legal/Institutional Framework					
Strengthening enforcement of regulations (including penalty systems)	+	+	+		+
Stricter limits on groundwater use	+ (for industry)	+		+	+ (except for individual use)
Coordination of existing organisations		+			+
Establishment of new authority to allocate GW	+				
Financial Tools					
Increase of charge for groundwater use	+	+	+		
Charging for agricultural groundwater use	+				
Improvement of charging system (from flat to progressive)	+				
Private sector involvement in groundwater charge collection		+			
Compensation scheme for conciliation of water conflict					+
Establishing a groundwater market	+				
Water Resource Management					
Integrated basin water resource management		+	+	+	+
Artificial recharge of aquifers	+	+	+		
Redefinition of the Critical Zone	+	+	+		+
Reduction of water loss/ enforcement of water saving			+		+
Water demand management	+				
Land Use					
Zoning		+			
Reallocation of industries	+	+	+		
Related to Alternative Water Resources					
Development of surface water including construction of artificial dams		+			
Implementation of water transmission				+	
Water supply scheme for industries	+	+			
Promotion of wastewater reuse		+	+	+	
Rainwater harvesting		+	+		+
Promotion of blackish water use				+	
Desalination of seawater				+	
Pollution Control					
Surface water pollution control					
Construction of wastewater treatment facilities		+	+	+	
Implementation of Polluters Pay Principle (PPP)	+				
Encouraging cleaner production (CP)		+	+		
Enhancement of pollution controls in the agricultural sector			+		
Introduction of new discharge standards					+
Scientific Data on Groundwater					
Improvement to groundwater monitoring	+	+		+	+
Improvement to database system	+				+
Further studies about groundwater management issues	+			+	+
Proper definition of safe drinking water					+
Others					
Encouraging public participation	+			+	+
Encouraging public awareness		+	+	+	+
Capacity building	+				

CHAPTER 3

SUMMARY OF CASE STUDIES

This chapter is the compilation of the summary reports of SWMP case study cities shown in the following figure. The reports presented the information and the facts are the basis of analysis and recommendations in the previous chapters.

Each case study consists of facts and figures relevant to groundwater resources and its management. The studies then focused on other water sources related to groundwater management in the respective studies. Lastly, the case study shows the recommendations specifically to the case study cities which were developed by the SWMP research partners. In the formulation of recommendations, stakeholder meetings were held in each city to hear more diverse view and ideas from the participants with differing backgrounds.

Figure . SWMP Case Study Cities

CHAPTER 1
CHAPTER 2
CHAPTER 3

CHAPTER 3-1

Sustainable Groundwater Management in Bangkok

The research on Sustainable Water Management Policy (SWMP) initiated by the Institute for Global Environmental Strategies (IGES) aims to propose integrated policy options for sustainable water resources management in urban and peri-urban areas of Asia with a focus on groundwater resources. Case studies that provide synopses of water resources management and use practices in several areas in the region were conducted, and IGES has collaborated with the Water Engineering and Management (WEM) Field of Study of the Asian Institute of Technology (AIT) for performing the case study for Bangkok, Thailand. The Bangkok Case Study aims to obtain an overview of water resources use and management practices—particularly for groundwater resources—in Bangkok. The existing policies on groundwater management in Bangkok are analyzed and improvements needed in this direction are recommended.

1. 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).

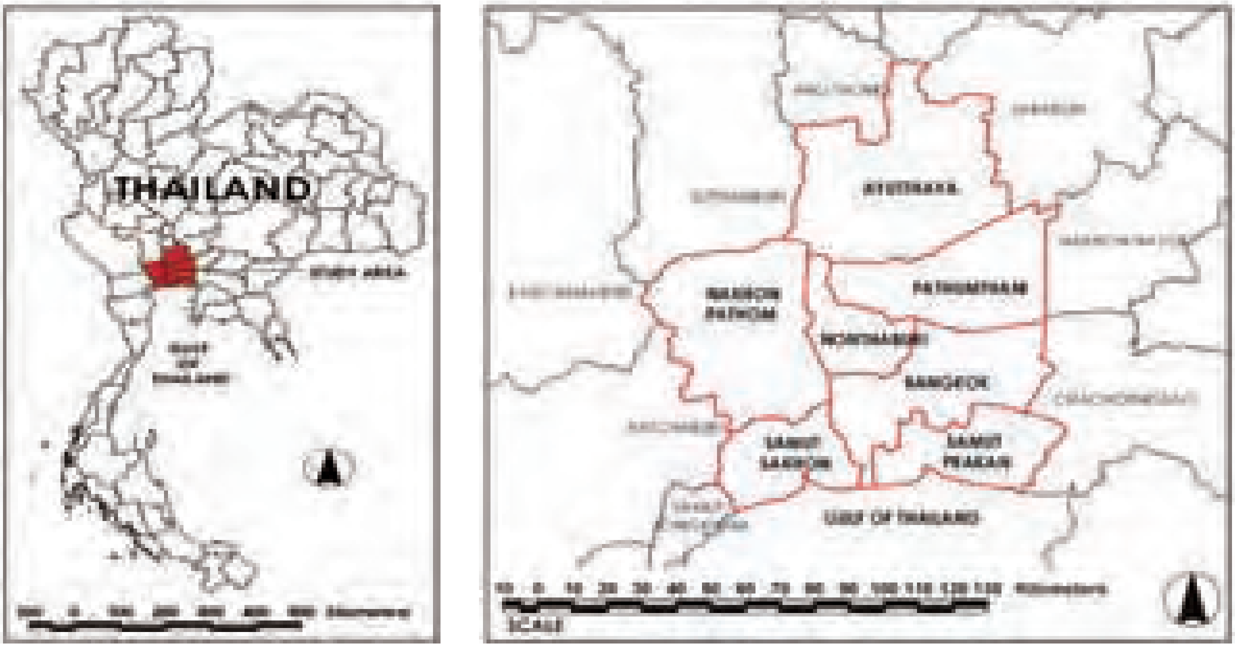

Figure 1. Thailand Case Study Area

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 Kok 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 persons/km^2 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 about 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/year consisting of 16,900 million m^3/year surface water and 600 million m^3/year groundwater. By 2016, it is estimated that this amount will increase to more than 18,000 million m^3/year, comprised of 17,400 million m^3/year of surface water demand and 800 million m^3/year of groundwater demand (RID, 2000).

2. State of Water Resources

A large portion of Thailand's water resources is used for agriculture. According to 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/year 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 that 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/year in 1996, and that this will increase by about 22% to 1,335 million m^3/year by 2006 and by 34% to 1,469 million m^3/year 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 supply 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 in 2003. 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, a moderate increase in Samut Sakhon, and slow increase in Nakhon Pathom and Ayutthaya. Service coverage has been low, especially for Nakhon Pathom and Ayutthaya, where statistics show that PWA supplies water to only about 2–3% of the population in these provinces. In Samut Sakhon, the percentage of residents receiving water services from the 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.

3. Issues and Discussion on Groundwater Management

In Thailand, groundwater has primarily been developed for domestic and industrial purposes and used only as a supplement for surface water irrigation by the agricultural sector. However, in recent years a large number of agro-wells have been installed in the Study Area. 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.

3.1 Groundwater Use and Associated Problems

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/day from 8,360 m^3/day 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/day. It reached its peak in the late 1970s and early 1980s, amounting to 464,000 m^3/day 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).

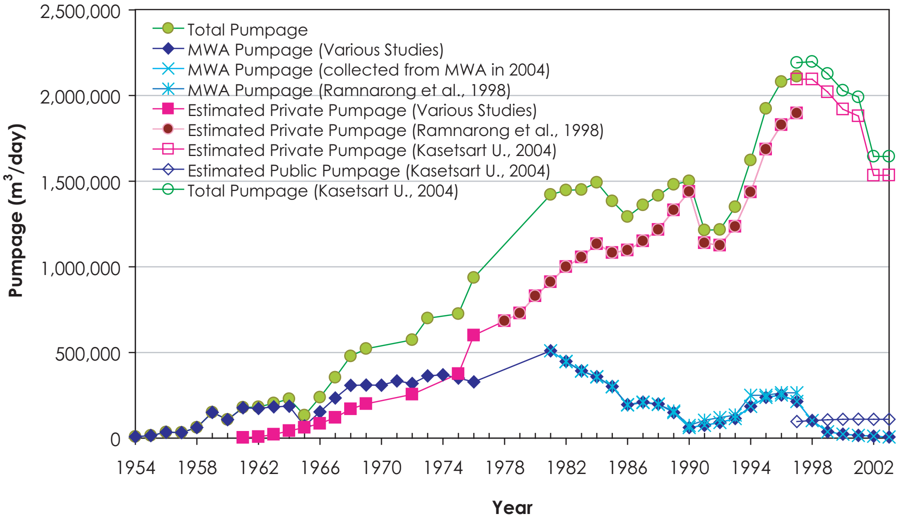

Figure 2. Groundwater Pumpage in Bangkok and Surrounding Areas
Source: AIT and DMR, 1978; Ramnarong et al., 1998; Kasetsart University, 2004

Recent estimates of groundwater use in the Study Area indicate that total pumpage by registered private wells has been around 2 million m^3/day since 1997, varying from 2.2 million m^3/day in 1997 to 2 million m^3/day in 2001, and decreasing to 1.7 million m^3/day 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/day 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/day, 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).

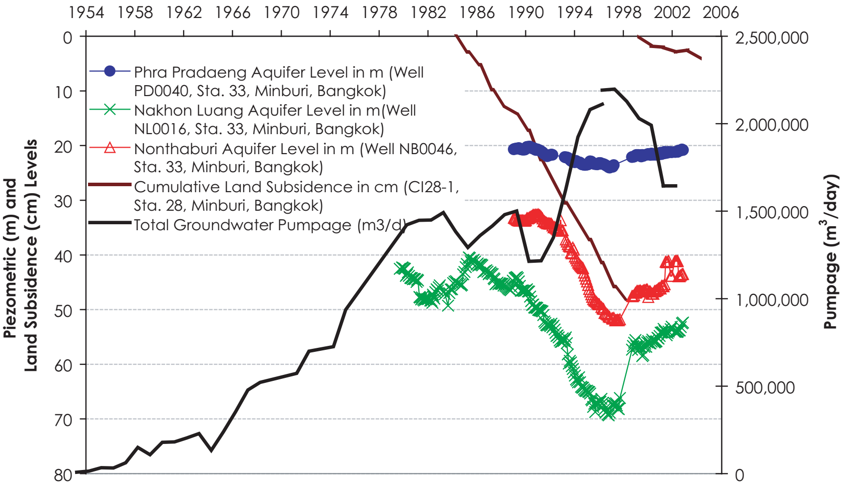

Figure 3. Total Groundwater Pumpage in Bangkok and Surrounding Areas, and Piezometric and Land Subsidence Level Variations in Minburi, Bangkok

Land subsidence has been a continuing problem in the Bangkok region for the past four decades, and the provinces comprising the Study Area have 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 pumpage. 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 land subsidence in central Bangkok in 1978 (figure 4) (AIT, 1981).

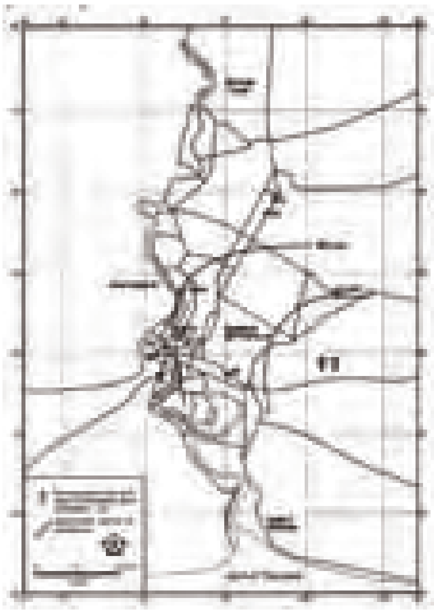

Figure 4. Subsidence in Bangkok from the First Leveling Survey by the RTSD in 1978
Source: AIT, 1981

An investigation program initiated by the National Environment Board (NEB) of Thailand in 1978–1981 showed irrefutable evidence 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/year. Maximum subsidence rates of more than 10 cm/year were detected in the eastern part of Bangkok. Piezometric observations 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/year 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 reduced to about 1 cm/year. 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/year was observed in 2003, as well as in Samut Sakhon located southwest of Bangkok (Kasetsart University, 2004).

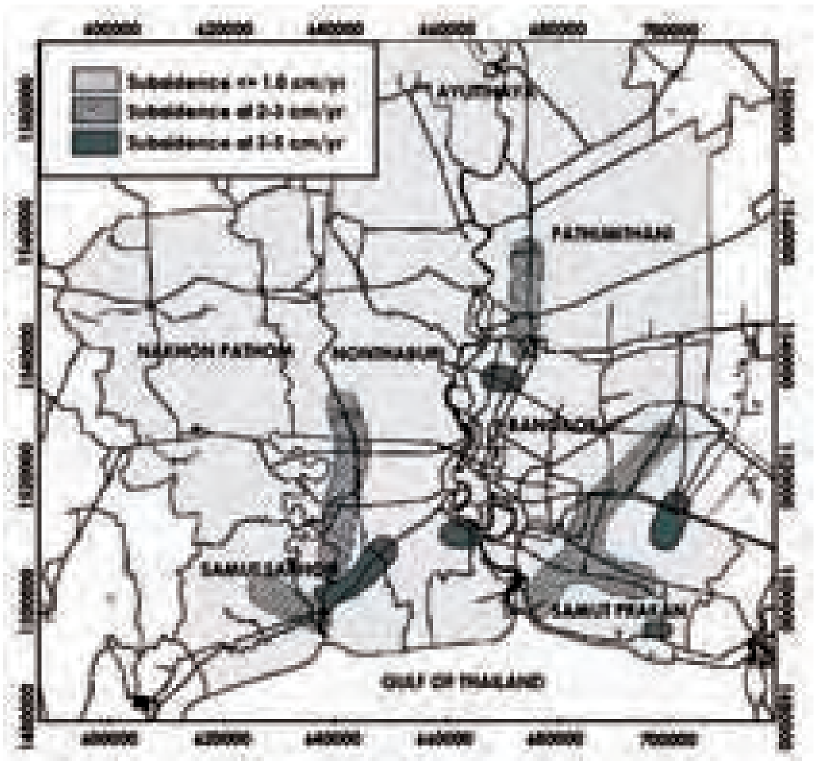

Figure 5. Map Showing Land Subsidence in 2003
Source: DGR 2005

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 strict 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 in around 1997, recovering afterwards although not up to the previous levels of the late 1980s (figure 6). The increase in groundwater levels provide a positive sign on the recovery of groundwater, but further studies might be needed to determine the safe yield, based on the increasing or constant water levels attained. These studies should also consider the domain for defining the safe yield, whether it has to be localized or specified for every aquifer.

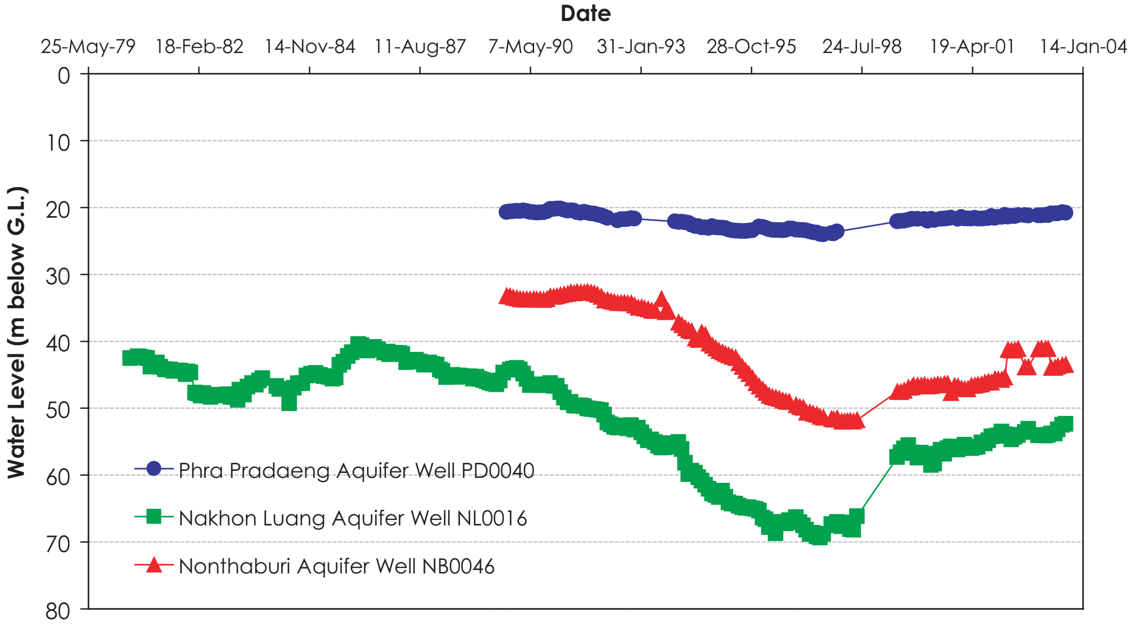

Figure 6. Groundwater Level Variation in Station 33: Minburi, Bangkok

As for groundwater quality, recent analysis of monitoring data from DGR has shown elevated concentrations of chloride (increased salinity) for the three most extensively 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).

3.2 Policy Responses and Future Challenges

Since the emergence of various problems associated with groundwater in the Study Area in the 1960s and 1970s the government has implemented numerous measures to mitigate these problems. These policies and regulations, which are of various types, include:

(1) 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 Critical Zones where more control over private and public groundwater activities was 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).

(2) 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 1.00 baht was charged for every cubic meter of groundwater used. By 1994, the charge was increased to 3.50 THB/m^3, and the government began to charge for groundwater use in the whole country. Between 2000 and 2003, the groundwater charge was gradually increased in the Critical Zone from 3.50 THB/m^3 (July 2000) to 8.50 THB/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 THB/m^3 (1 September 2004), the charge is set to increase to 8.50 THB/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 used in the Critical Zone has become relatively high compared to the piped water charge, which has helped in limiting the exploitation of groundwater in the area. The total groundwater charge increased from 9.50 THB/m^3 in 2004, to 12.50 THB/m^3 by mid-2005, and to 17 THB/m^3 by July 2006 and beyond. In a perception survey, industries responded that they will continue the use of groundwater even if the charges are increased; the maximum rate acceptable to them being 20 THB/m^3 of water used.

Levying surcharges and penalizing violators of regulations: According to the Groundwater Act, anyone not following the regulations will be fined not more than 20,000 THB, and those who use groundwater in declared Critical Zones or without licenses will be imprisoned for not more than six months and/or fined 20,000 THB and the drilling machinery and equipment confiscated. Registered private users who fail to pay for their use of groundwater on time are also penalized.

(3) 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 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). The database aids in planning and decision making for improved groundwater management.

(4) 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, including the artificial recharge of the depleted aquifers.

Public awareness programs: The 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. The effectiveness of the existing policy measures is described below:

Groundwater Well-Drilling and Use Licenses: 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 in 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 to obtain more accurate quantification of groundwater use and has ensured that users pay for exactly how much they extract and are not exceeding allowable amounts, all registered users do not comply to this regulation. Even though the Groundwater Act has helped the authorities to gain some control over the groundwater activities, illegal pumping still exists. The shortage in the number of DGR inspectors for monitoring the wells and other budgetary constraints act as hindrances in ensuring that all the private groundwater wells are registered. The system for information dissemination is also not effective. 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.

Some inappropriate legislation may also be considered as a hindrance 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.

Penalties and Fines for Violators: Punishment for lawbreakers range from a fine of not more than 20,000 THB 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 and may not be cost effective.

Establishment of a Groundwater Monitoring System: 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 and strategies. 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.

Control of Groundwater Use in Critical Zones: Limiting groundwater use in declared Critical Zones in 1983 was generally unsuccessful, sustained only in areas where alternative water sources were made available. Nevertheless, at present, groundwater pumping by MWA has been essentially curtailed, and estimates show a decreasing trend in private groundwater use since peaking at more than 2 million m^3/day in 1997.

Phase-Out of Groundwater Use for Public Water Supply by MWA: The earlier attempts of MWA to totally phase out use of groundwater for supplying water to its customers in 1983–1987 were unsuccessful. Nevertheless, the agency has continued to improve its distribution system, increase production capacity, and increase raw surface water abstraction and thus is successful in completely stopping the groundwater pumping for public water supply.

Groundwater Use Charge: The effectiveness of levying charges for groundwater use in controlling private groundwater abstraction has been limited. Without alternative sources of water, consumers have no choice but to continue using groundwater. Also, groundwater use charges are not levied for agricultural groundwater use.

Metering of Groundwater Wells: The effectiveness of this control measure has been limited by the fact that not all registered users conform to the regulation. Although groundwater users will have to pay for the full allowable amounts (even if they actually use less) when their wells are un-metered, this has not driven them to abide by the regulations, perhaps because the existing system of groundwater-use reporting by the consumers themselves, wherein well owners report their monthly use to the DGR, who in turn bills them for their consumption, does not really incite groundwater users to do so. The DGR has a policy of inspecting groundwater use for each registered well at least once every two months, but they are unable to do so because of a shortage of inspectors.

Groundwater Preservation Charges: Unlike the water user charge, there is a flat rate for the preservation charge. This has to be based on the different sectors, i.e. greater charges for those sectors using more groundwater.

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.

3.3 Proposed Policy Options for Sustainable Groundwater Use

Policy options which can mitigate the groundwater-related problems in the Study Area were drafted in the first stakeholders' meeting, conducted in July 2005. The proposed policy options were analyzed for their feasibility and effectiveness, and suitable paths for implementation—as well as implementing agencies—were identified in the second stakeholders' meeting conducted on April 2006. Suitable policy measures to resolve the issues on groundwater management in the Study Area, as developed in the two stakeholder meetings are as described below:

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 to pardon currently unregistered groundwater users and ask them to register with DGR.

Stricter limits on industrial water/groundwater use: Reduction of water/groundwater use by industry may be advanced through provision of incentives for the recycling and reuse of water as well as the promotion of clean technologies. Safe yields need to be specified for different areas and suitable quotas need to be established for groundwater use in the industrial areas, within the safe yields. Further studies need to be conducted in this direction.

Relocation of large groundwater users, such as industries, outside the Critical Zone: A study was conducted to determine the technical, economic, and environmental feasibility of this approach, but it is difficult to implement. This measure needs financial incentives from the side of Government, to be implemented. Rather than relocating the existing industries, the new industries can be started 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. Another alternative to this is to have a Ministerial Notification designating the depth of groundwater wells as 15 m below the ground, throughout the country.

Modifying Groundwater Preservation Charge rates: A flat rate for the 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 of Groundwater Preservation Charges.

Implementation of Polluters Pay Principle (PPP): The Polluters Pay Principle, if implemented based on either the amount of wastewater produced or on the pollution load, could help in reducing the groundwater quality deterioration. The reduction in the amounts of wastewater will also result in more rational use of groundwater by industries.

Establishing a groundwater market: An efficient allocation of the depleting groundwater resource can be obtained by establishing formal markets, but requires appropriate infrastructure as well as legal and institutional arrangements.

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 the DGR. Recharging water into aquifers through a system of wells will not only help increase piezometric levels, it will also assist 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 the 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 the 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 the 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 resources 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 seminars and training, 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 further studies about groundwater management issues: Further studies need to be initiated on measures such as artificial recharge of groundwater and on the safe yield aspects which can help in sustainable groundwater management.

Given the issues mentioned above, there is an increased need to consider the sustainability factor in the use and management of groundwater resources in the Study Area. This demands immediate measures to be taken to rationalize groundwater use, which has to be prioritized starting from the heavy users. The case study has identified the industrial sector as the major user of groundwater in the Study Area, with around 69% of the total groundwater use in the seven provinces. Considering the pace of industrial development, it is expected that there will be a corresponding increase in industrial groundwater use. Hence, immediate measures need to be taken to rationalize the amount of groundwater used by the industries. This is made possible only if alternate sources are made available to meet the water demand of the industries. The development of suitable alternative sources which can supply water to the heavy users of groundwater has also been identified as a suitable option for sustainable groundwater management by the stakeholders. Hence a study on alternative water resources was also conducted to consider its feasibility as a measure to rationalize groundwater use in industries.

4. Issues and Discussion on Alternative Water Resources

The study on alternative water resources focused only on three provinces due to time and data constraints. Bangkok, Nonthaburi and Samut Prakan provinces, which are being supplied by a piped water supply from MWA, were selected for this study. Water use in the Study Area as of 2003 is given in figure 7. The surface water supplied by the MWA accounts for about 90% of the total water use, consisting of 48% residential use, 51% non-residential use and 1% public supply and other uses. The non-residential use includes business, state enterprises, government agencies and industries. Groundwater use is constituted of 60.8% industrial use, 38.6% domestic use and a mere 0.2% agricultural use. Even if the amount of groundwater used is only 10% of the total water used in the three provinces, the effects of groundwater pumpage such as land subsidence and groundwater level decline is seriously felt in this area, which points to that fact that groundwater resources are still overexploited.

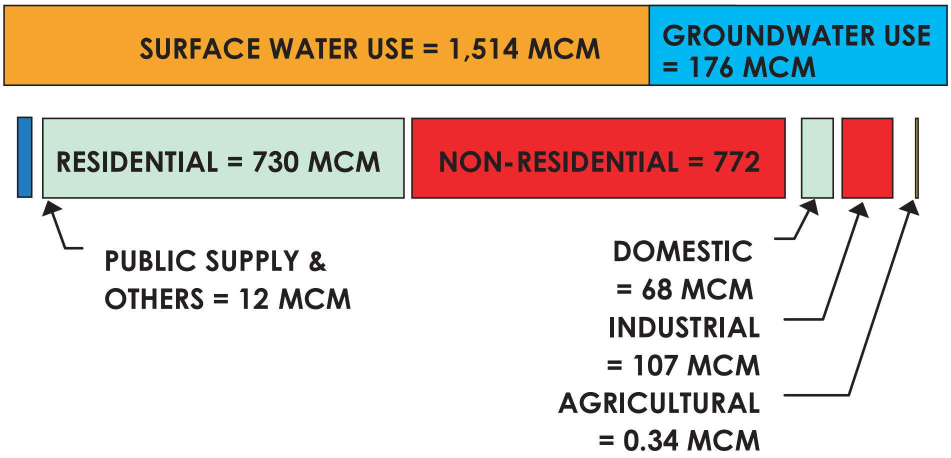

Figure 7. Current Water Use by Various Sectors in Bangkok, Nonthaburi and Samut Prakan, for the Year 2003
Note: MCM means million/m^3

As is the case for the seven provinces, the industrial sector is the largest user of groundwater in these three provinces as well, accounting for about 61% of the total groundwater use. Hence the study on alternative resources was focused on the industrial sector. The percentage of groundwater use in total use is further broken down for the three provinces in the Study Area as given in Table 1. 76% of the total water supplied by MWA is to Bangkok, and only 5% is supplied to Samut Prakan. This might be the reason for the higher percentage of groundwater use in Samut Prakan, when compared with the other two provinces. The actual percentage will still be higher considering the fact that there are a large number of shallow agro-wells which are not registered with the DGR, and also the groundwater pumpage given includes only the requested pumpage at the time of registration.

Table 1. Percentage of Groundwater Use in the Total Water Use by Three Provinces, for the Year 2003

Province	Total water use (million m^3)	Surface water use (million m^3)	Groundwater use (million m^3)	GW use in total water use (%)
Bangkok	1340.14	1289.84	50.30	3.75
Nonthaburi	160.81	130.32	30.49	18.96
Samut Prakan	188.30	93.54	94.76	50.30
Total	1689.25	1513.70	175.55	10.39

If this groundwater use needs to be reduced or brought to amounts which are not detrimental to the environment, the most significant option to be considered is the provision of other alternatives from which the water demand of the particular sectors can be satisfied. At the stakeholders' meetings conducted in July 2005 and April 2006, the stakeholders recommended the development of alternative water sources for industries. The alternative options identified as a result of stakeholder dialogue included expanding the piped water supply by the MWA and PWA, promoting wastewater reuse and recycling in industries, and establishing an industrial waterworks authority with the sole purpose of supplying water to the industries. However, the option of having an independent industrial waterworks authority might not be economically feasible in the Thai context, so the study focused on only two alternatives: expansion of piped water supply and promoting wastewater reuse and recycling.

For the study on alternative water sources for industries, it is important to analyze the present situation of groundwater use by industry and also the reasons for industrial preference of groundwater. To obtain primary information on industrial groundwater use and their level of adoption of the proposed alternative sources, a perception survey was conducted. A stakeholders' meeting with a particular focus on industry was also organized for obtaining information on the various measures to be adopted for rationalization of industrial groundwater use, especially on the feasibility of providing the proposed alternative water sources. Secondary data and information were also collected from relevant government agencies and related literature.

4.1 Perception Survey and Stakeholder Meeting

A perception survey was conducted with the objective of obtaining the views/perceptions of industries on the rationalization of water use and on the possible alternatives for groundwater. The survey was conducted only in Samut Prakan province. Groundwater use is at a maximum in Samut Prakan province, as seen from table 1. Also, considering the various uses, industry uses groundwater the most intensively (71%), as shown in figure 8. Hence industries in Samut Prakan were chosen for the perception survey. The survey was conducted via personal interviews and mailed questionnaires. A sample of 80 industries was selected for personal interview from the industries which use more than 300 m^3/day of groundwater and questionnaires were mailed to 400 industries. The response rate for the interview was 70% (56 respondents), whereas that for the mail survey was only 7% (29 returned). The total number of respondents (both interview and mail) was 85. The survey has shown that 55% of industries depend on groundwater either alone or in combination with piped water supply from MWA. Considering the amount of water used, only 24% of the total water used in the industries comes from groundwater (table 2).

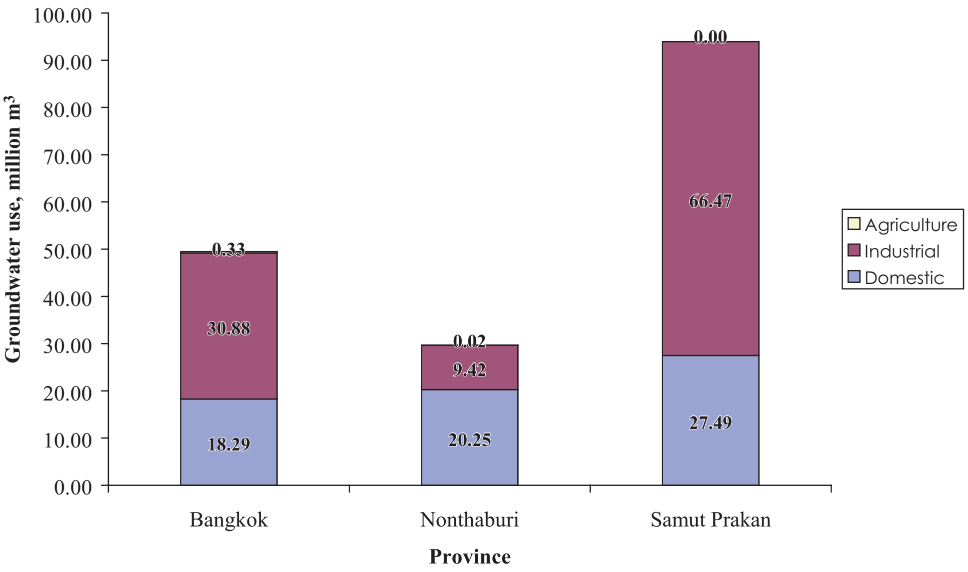

Figure 8. Groundwater Use by Different Sectors in Bangkok, Nonthaburi and Samut Prakan in 2003

Table 2. Dependency of Industries on Different Water Sources and Water Use

Type of industry	Industries using piped water (%)	Industries using only groundwater (%)	Industries using both piped water and groundwater (%)	Piped water in total water use (%)	Groundwater in total water use (%)
Textile	37	7	56	35	13
Food	42	5	53	17	4
Chemical products	43	14	43	2	5
Automobile	67	0	33	9	0
Leather & footwear	0	33	67	0	0
Metal	67	17	17	4	1
Electrical & electronics	33	0	67	7	0
Paper	25	0	75	1	1
Building material	100	0	0	1	0
Plastics	100	0	0	0	0
Total (%)	**45**	**7**	**48**	**76**	**24**

The preference for groundwater by industries is attributed to the following reasons:
No MWA supply earlier: At the time of establishment of some industries, MWA piped water supply was not available in the area, therefore industries had to opt for groundwater pumping. However, there has been a shift from groundwater to piped water use during recent years due to the expansion in coverage of MWA supply and now they retain the groundwater wells as a reserve to use in times of emergency.

Piped water supply quality is not suitable for the industries: The presence of chlorine used for water treatment of piped water for meeting the domestic water quality requirement is not acceptable to some industries, for example in the textile, food and chemical industries.

Industries are not satisfied with the reliability of piped water supply: The industries surveyed have expressed concern over the stability and reliability of the piped water supply. Sometimes the piped water supply is shut down without any prior notice, and this affects production in the industries. Also, a major concern raised by the industries on piped water is that the supply does not satisfy the required pressure at all times.

For determining the effectiveness of the alternatives, a stakeholder meeting was conducted. The stakeholders were also provided examples of success of alternatives such as the introduction of industrial water works and wastewater reuse and recycling in Japanese industries. The discussions also aided in the evaluation of alternatives such as expansion of piped water supply and wastewater reuse and recycling in the Thai context.

The survey results and stakeholder meeting have shown that industries started using groundwater when they did not have access to MWA supply in the area and that the quality and pressure considerations of piped water supply are also factors contributing to their preference for groundwater. This shows that if piped water supply is expanded so that the industries are provided with a reliable and sufficient supply at the required quality and pressure, it can act as an alternative to groundwater. Also, the stakeholders, while evaluating the feasibility of policy recommendations, have identified expansion of piped water supply by MWA and PWA as possible options for addressing the groundwater-related problems.

4.2 Expansion of Piped Water Supply

The MWA is responsible for providing piped water supply in the three provinces considered for the study on alternate water sources. At present, the MWA covers less than 50% of its area of responsibility and provides domestic supply to about 90% of the population. According to the revised master plan for water supply and distribution by the MWA, it is expected to increase the pumped water capacity from 4,063,491 m^3/day in 2002, to 5,727,552 m^3/day (an increase of 40.9%) in 2017. The population coverage is targeted to reach 100% by 2017. For the MWA, the priority is to provide water for domestic consumption. However, the expansion plans should also consider providing the required quantity of piped water to industries. Areas in which there is a greater concentration of industries need to be prioritized in this regard.

The Principal Plan for Industrial Water Management developed by the Department of Industrial Works (DIW) states that the policy banning groundwater use by industries in Bangkok Metropolitan Region has prompted the need for industries to use raw water of 1.4 million m^3/day. A mathematical model study by Kasetsart University (2004) has determined the reduction in groundwater pumpage by the private sector, mainly the domestic and industrial sectors, due to the expansion of MWA services. Accordingly, it is expected that by 2013 there will be a reduction in groundwater use of around 0.32 million m^3/day given the replacement of 5,294 groundwater wells as a result of MWA expansion, as given in table 3. This is, however, based on the MWA expansion plans of 1990.

Table 3. Reduction in Groundwater Pumpage by Expansion of MWA Services

Year	Yearly		Cumulative	
	No. of wells replaced	Reduction in groundwater use (m^3/day)	No. of wells replaced	Reduction in groundwater use (m^3/day)
2004	2,597	130,490	2,597	130,490
2006	1,430	89,590	4,027	220,080
2010	582	40,080	4,609	260,160
2013	685	55,850	5,294	316,010

Source: Kasetsart University, 2004

According to the perception survey, 45% of the industries are using only piped water. The expansion of piped water supply can be an option to increase the surface water use by those industries which are currently depending on groundwater. The main issues associated with piped water which are not admissible to industries include the quality and reliability of supply. If the expansion plans of the MWA consider providing water continuously and at the required pressure, the industries can use a piped water supply with appropriate treatment, if required at the industry level.

The presence of chlorine in piped water is an issue for some industries, such as the textile, food and chemical industries. As the main concern of the MWA is to provide water for drinking purpose, it needs to be disinfected according to the WHO guidelines. It will not be financially feasible to have separate distribution lines for domestic and industrial purposes. But, this can be addressed by storing the piped water for a few (2–3) hours before use in the industrial process. A centralized elevated storage tank can be constructed in the case of industrial estates for this purpose. Water from this centralized elevated storage tank can be provided to the individual industries at the required pressure and quality. For example, of the 52 groundwater wells in the three industrial estates in Bangkok, the Industrial Estate Authority of Thailand (IEAT) has decided to maintain only 25 wells as reserve in case of emergencies, such as shut down of piped water supply by the MWA. Centralized storage tanks will be constructed and industries will be supplied with piped water, but at a slightly higher tariff than that charged by the MWA.

Also, a major share of the water used in industries is for cooling, as boiler feed and for cleaning, and these processes do not require a high quality of water. Hence, the industries that are heavy users of groundwater can shift to using piped water in those processes in which quality is not of much concern.

Presently, the percentage of coverage by the MWA with respect to area is only around 50%. The investment cost is high for laying out pipelines if the industries are far from the main pipeline. But in the third stakeholders' meeting, the MWA expressed its willingness to support the industries with respect to the cost of the pipeline system and the MWA would consider such requests on a case-by-case basis.

A significant impediment in using piped water as an alternative water source by industries using groundwater is the resistance to change. The groundwater users are reluctant to use piped water, as they are not sure of the problems they would face if they shift to piped water and hence they are not ready to take risks.

The MWA is also trying to promote the use of piped water by industrial sector. As part of the promotion plan, piped water is initially supplied at a lower rate of 13 THB/m^3 to the industries. When the industries become convinced with the supply reliability and quality, they start using more piped water and after three years the normal tariff is charged. Such promotion measures, if coupled with other incentives from the Government, can help increase the use of piped water by the industries that are heavily dependent on groundwater.

4.3 Wastewater Reuse and Recycling

Wastewater reuse and recycling, if adopted in industries, can help better efficiency of water use and results in water and cost savings. Recycled and reuse water are considered alternative resources and should be taken into account for water resources planning and management. This has been very successfully implemented in various industrialized countries like Australia, Germany, Italy, Japan, Singapore, the United States, etc. (Urkiaga, A., 2004). As an example, in Japan, in spite of rapid industrial development, the industrial sector has reduced its dependency on groundwater and shifted to using more recycled water. The percentage of recycled/reuse water use has increased from 21% in 1960 to about 80% in 2000. These success stories can be adopted in Thai industries as well, with suitable modifications to suit Thai conditions.

Reuse and recycling are adopted as strategies to improve water use efficiency in industries in the National Water Strategies developed by the Water Resources Association of Thailand. However, presently wastewater reuse and recycling are adopted as waste minimization techniques rather than as water-saving measures. The National Integrated Waste Management Plan has adopted the 3Rs (Reduce, Recycle and Reuse) as the major strategy. The National Master Plan on Cleaner Production (CP) developed by the former Ministry of Science, Technology and Environment has the vision of controlling pollution and management of natural resources and environment. The DIW, in its 'Principal Plan for Industrial Water Management,' states the need for adopting these practices in industries. It also underlines the necessity of reducing groundwater use by industries.

Transfer of technology as a measure for capacity strengthening in the DIW, with respect to the effective use of water in industries, is provided by the Japan International Cooperation Agency (JICA), which also resulted in the setting up of an Industrial Water Technology Institute (IWTI) (JICA and DIW, 2000). A Cooperative Research Project on the Development of Environmentally Friendly Industrial Wastewater Reuse Technology is being undertaken by DIW in collaboration with the New Energy and Industrial Technology Development Organization (NEDO), Japan. The target group of industries for the project includes the textile and food industries.

From the perception survey, it was observed that there is a fairly good adoption, with 59% of the surveyed industries adopting wastewater reuse and recycling practices. The survey has also shown that 31% of the industries reuse/recycle wastewater in the cleaning process, 16% used for cleaning, 23% in boilers, 19% in cleaning machinery and 23% in uses other than in production processes, such as watering plants, cleaning floors and flushing toilets. Many of the industries, which are in the process of applying for ISO 14000 certification, are planning to incorporate wastewater reuse as their future management goal.

The industries, being profit-oriented, will adopt wastewater reuse and recycling only if they prove to be cost-effective and competitive. The MWA piped water is supplied at a charge of 16 THB/m^3. Hence, if they are to adopt wastewater reuse and recycling, it should be comparatively cheaper in terms of investment and recurring costs.

Pilot studies on Cleaner Production (CP) technologies conducted in Carpets International Thailand PCL (CIT), also determined the efficiency of input use and technical and economic feasibility of reuse and recovery. It was found that the cost for modification of the existing systems and for upgrading the wastewater treatment plant to accommodate separate treatment of wastewater amounted to 12 million THB and the expected water saving by recycling was equivalent to a saving of 7 million THB/year in water bills. This brings the payback on investment for reuse and recycling to less than 1.7 years. Thus, the adoption of these practices was found to be economically feasible (Franknel, R.J., 2005).

Even though wastewater reuse and recycling can be economically feasible, there are some institutional and management issues associated with the large-scale adoption of the practices in the Thai industries, as mentioned below:

Institutional and Management issues: No legislative arrangements are in place to promote wastewater reuse and recycling. Also, there are no proper guidelines for the implementation of the practices. Industrial wastewater reuse/recycling are being practiced as measures to control pollution, which is the responsibility of many agencies. There is a lack of proper coordination between these agencies and industries. The industries are not fully aware of the advantages of water saving by the adoption of these practices. The lack of incentives and subsidies from the Government side are also bottlenecks in the widespread adoption (Viswanathan and Cippe, 2001).

Potential policy approaches that can be followed for widespread adoption of wastewater reuse and recycling in Thailand are as follows:

i. Legislation and regulations for wastewater reuse and recycling should be in place, and it should focus more on potential water savings in industries.
ii. Financial incentives from the Government side are needed for successful implementation. The reuse and recycling processes, if adopted, need additional treatment facilities, which require high investment cost. The

financial incentives can be either as support in the initial investment or as a tax refund/discount for those industries adopting the practices.

iii. The development of industrial wastewater reuse permit structure and guidelines.

iv. The industries in which reuse and recycling has to be adopted should be prioritized based on factors such as their water consumption or pollution load. Water productivity benchmarks need to be established to increase industrial production using less water.

v. The regulations on pollution control also need to be effectively implemented, such as the collection of wastewater discharge fees. Fines need to be collected for non-compliance of regulations.

vi. Better co-ordination needs to be achieved between the different agencies such as the DIW, IEAT, FTI and individual industries for successful implementation. An alternative that can be adopted is that the group of industries in the industrial estates can join together to have a wastewater treatment plant and the treated water can be supplied to the individual industries.

vii. Research and development on the technology that is suited to the Thai context should be promoted.

viii. Creating awareness among the industries, especially Small and Medium Enterprises (SMEs), on the cost savings and water savings that can be achieved by adopting wastewater reuse and recycling.

5. Conclusions

Extensive use of groundwater in the Bangkok Metropolitan Region started in the mid-1950s primarily for public water supply. But, at present, private usage of groundwater has become more significant, mostly by the industrial sector. Of the eight layers comprising the aquifer system, the most utilized are the second (Phra Pradaeng), third (Nakhon Luang), and fourth (Nonthaburi) layers from the ground surface. Over-exploitation of groundwater has resulted in various environmental problems, such as extreme lowering of water tables, land subsidence, and increased salinity of aquifer yields in the Study Area. These problems led to the formulation of various mitigation measures by the Government of Thailand, such as promulgation of the Groundwater Act, defining critical zones, licensing and metering of groundwater wells, introducing groundwater use and preservation charges, etc.

Nevertheless, groundwater-related problems still exist in the Bangkok Region. Hence, improvements are needed in the existing policies and new policies need to be formulated. Through this research on SWMP (Sustainable Water Management Policy) integrated policy options for sustainable groundwater resources management in the Study Area are proposed. The proposed policies include direct control, economic, supporting, technical and informative measures. As the industrial sector is the major user, alternative water sources for rationalizing the groundwater use in the industries, such as expansion of piped water supply and wastewater reuse and recycling, are also proposed. For the industries to shift from groundwater to piped water supply, good quality of water with a reliable supply has to be ensured.

To be able to translate policy proposals to concrete actions, it is recognized that proper enabling environments for implementation must be established. Proposed new or improved measures developed on the basis of sound knowledge are good starting points. But, 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 and activities requires much time and effort from the concerned authorities.

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CHAPTER 3-2

Alternative Water Resources and Recycle Program as Effort to Strengthen Ground Water Management in Metropolitan Bandung

1. Background to the Study Area

Groundwater differs from other water sources in that it takes a long time for groundwater to gather and fill its aquifers. As this is often overlooked, it makes groundwater vulnerable to over-exploitation. This unconscious imbalance between the natural recharge rate of groundwater and its abstraction has a broad impact. The question which often arises as to why groundwater is used so much more than other water resources. Approached in economic terms, this is a natural resource, available and ready to use without processing or high cost. The quality is relatively stable and usually meets health standards or process production standards more than surface water resources which fluctuate greatly depending on weather and other factors. In economic development terms, groundwater can be used to support human activities, including social, developmental and economic. All these conditions exist in the Metropolitan Bandung area. Groundwater use has become a primary source for supplying various activities in the Bandung area. Along with the population growth rate in Metropolitan Bandung, which has reached 2.7% (based on analysis of Statistical Data 1986 –2000), the demand for water for domestic needs is continually increasing. Increasing use of groundwater by industry puts pressure on water resource quantity, particularly groundwater. At present, nearly 70% of domestic water and approximately 60% of industrial water needs are satisfied by the use of groundwater, though groundwater accounts for only 10–15% of the available water supply. Meanwhile, increasing water pollution from both industrial and domestic wastewater puts pressure on the quality of surface water.

Research reveals that in deep aquifers almost 43% (113 million m^3/year) of the flow rate of groundwater which is exploited showed an imbalance between recharge rate and the abstraction rate of groundwater. In contrast, middle and shallow aquifers are relatively safe. Of 329 million m^3/year of domestic water needs in Metropolitan Bandung, approximately 150 million m^3/year is provided by shallow groundwater from residents’ wells, while 76 million m^3/year is provided by the Water Supply Enterprise (WSE), including 12 million m^3/year taken from several wells which are still producing. Groundwater used by industry, however, shows an increasing trend. Data of groundwater use from this sector (Environmental Geology and Mining Agency, 2005) noted that more or less 51.4 million m^3 of groundwater, especially deep aquifer sources, is utilized in this sector. Dependence of industry on groundwater is still high; data in 1993-2000 showed that nearly 60% of industry used groundwater to fulfil its needs. This is because the WSE supply for industry of is still very low, supplying 2.9% of total industry needs. Meanwhile, dependence on surface water sources, i.e. rivers, still faces obstacle in terms of both quantity and quality. In the wet season, minimum discharge of the main river, the River Citarum and its tributaries, tends to decrease, while in the rainy season, entering run-off can be uncontrolled. The decline of groundwater quality also occurred, particularly at the Citarum River. The impact of these factors in Metropolitan Bandung is water table depletion in several places caused by extreme exploitation, as well as land subsidence as a further impact of that water table depletion (Abidin, et All. 2002). From the preliminary survey conducted by the West Java Environmental Protection Agency, it is estimated that the radius of the affected area could reach at least 2km^2.

To avoid further possible negative impacts, there must be a prioritized policy. According to the research and water resources development plan, maximizing surface water resources and gradually stopping groundwater use is the most appropriate policy for Metropolitan Bandung. Additionally, an increase of water recycling programs for industry can help to recover groundwater sustainability.

1.1 Location of Study Area of Metropolitan Bandung

The Bandung Basin, a plateau encircled by mountains that forms a basin, is located between 7°19' and 6°24' south latitude and 106°51' to 107°51' east longitude. That is one of Java's largest watersheds. It is located in the province of West Java and encompasses an area of 234,088 ha; the basin includes four administrative areas: two regencies (part of Bandung and Sumedang) and two cities (Bandung and Cimahi). It provides water for drinking, agriculture, and fisheries, as well as being the main water supply for three reservoirs, which have a total volume of 6,147 million m^3 (Wangsaatmaja, 2004). These reservoirs supply water for 300,000 ha of rice fields, and their hydroelectric dams are important energy suppliers for the islands of Java and Bali. In 2003, the population in Metropolitan Bandung was approximately 5,854,340, and is predicted to reach 9,706,363 in 2025. The average density is 340 persons/km^2. Figure 1 depicts the administrative boundaries of the Bandung Basin.

Figure 1. Map of the Administrative Boundary Defining the Bandung Basin
Source: Wangsaatmaja 2004

2. State of Water Resources

2.1 Surface Water

Ten main rivers which flow are classified as Citarum River tributaries. Its main river flows from east to the west and ends in the Saguling Reservoir. This basin is used mainly for water power plant and agriculture needs in its lower course and is not only used for the surrounding area, but also for supporting other activities. Of the tributary rivers that flow to Citarum River, it has been identified that some have more potential to be developed. Further explanation will be given about potential of the tributary rivers in the Citarum River Area. According to existing data (Regional Office of Public Works, 1996), surface water resources supply potential is quite abundant. According to calculations by the Regional Office of Public Works, surface water resources used account for 899.86 million m^3, or 53% of total of existing surface water supply, while the flood unit which almost happens every year has not yet been considered. More details can be viewed in surface water resources in table 1.

Table 1. Surface Water Resources

No	Sub River Basin	Water Supplying		Water Used		
		Normal	Minimum	Irrigation	Raw Water	Total Used
				(million m^3/year)		
1	Cimahi	75.06	10.41	37.29	5.05	42.31
2	Cibeureum	71.72	10.40	27.05	0.95	28.00
3	Cikapundung	152.32	21.13	29.25	25.86	55.11
4	Cipamokolan	153.9	21.13	0.00	0.00	0.00
5	Cikeruh	131.51	18.29	86.44	0.00	86.44
6	Citarik	209.08	29.33	181.4	1.89*	181.40
7	Citarum Hulu	251.97	35.00	103.92	0.00	176.05
8	Cisarea	0.00	0.00	72.13	0.00	0.00
9	Cisangkuy	379.69	52.98	153.52	42.26	195.78
10	Ciwidey	278.78	38.79	134.78	0.79**	134.78
	TOTAL	**1704.00**	**237.46**	**825.78**	**76.80**	**899.87**

Source: Regional Office of Public Works, 1996

* *It has been utilized for sumedang area*

** *Some water from Saguling lake has been operated and water industrial supply from surface water is relative low*

2.2 Saguling Reservoir

Saguling reservoir is the first reservoir of three in succession located alongside the Citarum River. This reservoir is an outlet from Bandung Metropolitan Area and has been in operation since July, 1986. Based on data from the Electricity Power Plant Institution in 2004, the average flow of the Citarum River into this reservoir is about 71 m^3/s. This reservoir is located in Bandung Regency. According to the operation procedure, "curve's guidelines" show that theoretical volume in Saguling Reservoir in 1996 for High Water Level condition is about 835.45 billion m^3 including surface area of 49.9 km^2, whereas in Lower Water Level condition created surface area is about 16.56 km^2. The report from the Electricity Power Plant Institution in 2003 shows that the theoretical volume in high surface water is about 806.5 million m^3 with a total surface area of about 48.6 km^2 and in lower surface water, the theoretical reservoir reached about 215 million m^3 with total surface area of about 16.3 km^2. The volume capacity changes because of sedimentation. In 1998, the data showed that capacity is decreasing by almost 30 million m^3. The draft for surface water operation is at the 623 m level and 643 m above sea level with a flood water draft of 645 m.

2.3 Spring Water Resource

Spring water resources are generally found in the upper area, which is a conservation area. Discharge of spring water registered is less than 2.768 m^3/s total and fluctuates depending on the season. These water resources are used significantly in rural areas (Gunawan, 1997)

2.4 Groundwater Resource

Based on groundwater quantity and quality (Warsono 1985 in Harnandi and Iskandar 1998) the area of study is classified into two areas of groundwater potential, namely (i) Areas with Moderate Potential of Groundwater in Shallow and Deep Aquifers and (ii) Areas with Moderate Potential of Groundwater in Shallow Aquifers and Low Potential in Deep Aquifers. Meanwhile, the Decree of the Minister Energy and Mineral Resources No. 716.K/40/MEM/2003 acknowledged that groundwater potency in Bandung Basin is divided into three groundwater basins: Lembang, Batujajar dan Bandung-Soreang, with classification of groundwater as confined or unconfined.

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

Groundwater Basin			Rank of Investigate	Amount of Groundwater (million 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	2	Inception	795	117

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

2.5 Rainfall Pattern in Metropolitan Bandung

Mean annual rainfall in Bandung Basin varies from 1,000 mm/year in middle shares to South-East of Bandung City up to more than 3,500 mm/year in North and less than 3,000mm/year in the South. The wet season is from November to April and the rest of the year is the dry season. Data analysis shows that yearly rainfall intensity ranges between 1,700-3,500 mm/year with mean value of 2,195 mm/year, average temperature is 22.6°C, and value of evaporate-transpiration 1,060 mm/year.

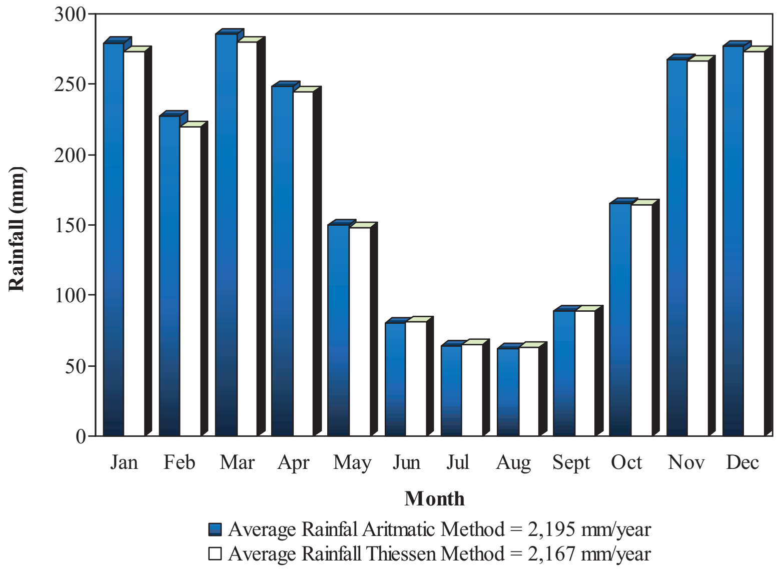


Figure 2. Comparison Rainfall Monthly Average in Bandung Basin 1950 -1999

Source: Raw Data coming from Metrological and Geophysics Bureau, 1950-2003

2.6 Water Supply Infrastructure

(1) Bandung City

The installed capacity on Water Supply Enterprises which has been reported is 3.5 m^3/s with 2.3 m^3/s derived from surface water. Mostly, the water resources are derived from Cisangkuy River and Cikapundung River, located in Bandung Regency Area. In 2000, the service scope is 40.40 %, of which 29.4 % is by direct connection. The domestic consumption in 2000 is 137 l/capita and the number has increased about 6 l/capita from 1996 (the domestic consumption in 1996 is 131 l/capita). On the other hand, the needs of non domestic units have decreased 10% in the last 5 years and in 2000, consumption reached 1.44m^3/connection/day. In 2000, the number of connections is 142,000, of which 90% consists of domestic connections (including public hydrants). The domestic service rate (including public hydrants which assume 100 people/hydrant) is 40% with 29% connected to housing. The condition of leaks in production before water goes into the distribution system has varied greatly in the last 5 years. The maximum leak rate was more than 5.9% in 1996 and was at its minimum of 2.4% in 1998. The leaks which were reported in 2000 were ± 4.6 % where 66% of standard water was derived from river. The leak maximum should be 4% whereas the leaks in distribution system has varied greatly between 45% and 47% (West Java Land Use Planning and Settlement, 2006). In most cases, leaks which happened were caused by physical problems.

(2) Bandung Regency and Cimahi City

Water Supply Enterprises of Bandung Regency and Cimahi City consists of the 18 systems with operation systems which include: (i) Main system, gravitation and pumps, especially in Cimahi with 184 l/s, (ii) Four system (Lembang-gravitation and pump, Batujajar and Pangalengan-both of them using gravitation system, and Soreang/ Banjaran-pump) with their capacity of 30-40 l/s, (iii) Four system (Cisarua dan Majalaya- both using gravitation systems, and Padalarang and Rancaekek, both using pump systems) with their capacity being 20-25 l/s and. The total usage capacity in 2000 was 450 l/s. The number of customer connections in 1998 was 3,600, where 40% were located in the Cimahi system area (with 96% domestic connections). Furthermore, domestic service scope (with public taps) is 8.2% of the total population in cities (with 6.5% private connections). Average domestic consumption is 105 l/capita/day, with an average of five people per household, so the community which does not have any fixed customer connections still has a possibility of using the clean water supply. In the existing report of 2000, 8.6% of the produced vanishes or leaks before getting into the distribution system. This is compared with 3% last year (West Java Land Use Planning and Settlement, 2006).

(3) Kabupaten Sumedang

The water supply in Sumedang block includes pipes systems and non-pipes systems. Pipes systems in Tanjungsari and Jatinangor district are maintained by Water Supply Enterprises of Sumedang Regency, and for Cileunyi District are maintained by Water Supply Enterprises of Bandung Regency. Water resources are derived from Walet Cave (Jatinangor River) which was built in 1992 with a design capacity of 135 l/s. Water supply systems using WSE pipes service 48% of the people in the Jatinangor sub district, and 83% of the people in the Tanjungsari sub district. The service rate in Tanjungsari and Jatinangor sub district is 66% of the number of people in Sumedang Block (Tanjungsari and Jatinangor). Water supply systems by using non-pipes are maintained by communities and households who mostly used shallow wells and pump wells (West Java Land Use Planning and Settlement, 2006).

2.7 Wastewater Infrastructure

(1) Bandung City

Wastewater disposal services for both liquids and solids in Bandung City (including middle area in Bandung City) which gravitationally flows to wastewater treatment installation in Imhoff Tank currently have not functioned optimally as a consequence of the excessive load. Thus, through Bandung Urban Development Projects I and II project, the centred system (off-site) has begun to extend to east and west areas clustering an old system which still uses the open system. The existing centre system has created two centred sub-system (West Java Land Use Planning and Settlement, 2006):

i. Eastern Area in which domestic waste water treatment plant has been installed in Bojongsoang.
ii. Some of the west area still has no wastewater treatment, so the river remains a disposal site, like the Citepus River in Karasak – South Bandung Area. The central sub-system consists of pipe networks and covered strips extending 318km^2, pump stations in the east area and 1 wastewater installation in Bojongsoang.

Nowadays, service area and catchments area are limited in the south area in the middle of Bandung which has developed to the east and west. The cost of new construction of central sewerage system for all areas is quite expensive, because the sewerage area is still limited. As a consequence, that service area is still very limited, and only includes 2,817 ha (17 % from total area in city). The existing service serves 1,500,000 people, or 65% of the population of which the centred wastewater treatment installation service scope is currently achieved ± 20 % as a consequence of tertiary and secondary wastewater treatment pipes, which still are limited.

(2) Local Sub-system Service Area (On Site System)

Local sub-system service areas currently include almost all of Bandung City Area except in the Middle and East of Bandung. The service area scope is 13,675 ha or 81% from a total area of a city which consists of 94 sub district. Most of the local system service is through individual septic tanks which serve 13,665 ha (80% of the Bandung City Area) with 202,000 units of septic tanks. Subsidence flows from septic tanks are distributed to infiltrate fields, but unfortunately the infiltrate field construction generally is still not supported, so that the septic tank finally distributes to drainage, and mixes with liquid wastewater from households. The disposal system using communal septic tanks can be found in several locations in Bandung City with a 10 ha-total area service, including Sarijadi Estate, Sadang Serang, Melong Asih and DPMB-Turangga Estate (West Java Land Use Planning and Settlement, 2006). The communal septic tank is generally made from ribbed steel and completed with infiltrate field with final disposal in nearest drainage system. However, because the sludge intake system from the communal septic tanks and infiltrate fields still does not function, the wastewater from septic tanks distributes to drainage which in turn pollutes rivers and other rivers downstream.

(3) Bandung Regency

Not every area in Bandung Regency is already served by wastewater and drainage service system. The cluster area which is served by wastewater and drainage service systems can be represented by the cities which are mentioned below (West Java Land Use Planning and Settlement, 2006).

a. Padalarang Sub District

Sewerage systems have not been made in every street; thus, the water from wastewater from households and rainfall cannot be distributed with wells. The current conditions show that some of the existing sewerage systems, especially those associated with human activities, have been pressed and choked so that they cannot accommodate water flows. Troughs for water disposal are generally available, although the quality is still not good. The sewerage systems with steel/concrete construction is available only in downtown whereas for another area the disposal site still generally consists of ground pipes, and they very often become plugged by grass. This causes some of the area in Padalarang sub district to become flooded, especially after the rain. Furthermore, the sewage system in Padalarang sub-district is very simple and limited. The existing communal sanitation facility is different in other city. Generally, the communal sanitation facility consists of septic tank system and direct communal sanitation facilities near or beside the river.

b. Soreang Sub District

The infrastructure of domestic wastewater disposal in Soreang sub-district consists of individual infrastructure and communal which uses both on-site and off-site systems. The on-site individual infrastructure consists of family toilet with or without septic tank, whereas on-site communal infrastructures have communal sanitation facilities and communal toilets. Furthermore, off-site infrastructure includes piping systems with Small Bore Sewer (SBS). Thus, the sludge from on-site system is drained with vacuum truck and disposed to communal fecal sludge treatment unit with wastewater which was collected through pipes on SBS. The domestic wastewater service scope is 78.8 %. Generally, drainage follows the street pattern with a flow course from west to east, which follows the topography in the area. The rivers which function as natural drainage are the Ciwidey and Cikambuy Rivers. Beside that, drainage has another function as final disposal from drainage in city, like the Leuwi Kuray Drainage which is located in north of the Soreang sub district. The drainage service area scope currently with sufficient quantity is still limited. Most existing drainage is still made from ground construction whereas the gutters of covered steel/concrete construction are still limited to the center of the city, especially at stations and shopping centers or traditional centers, and on main streets that formed as covered troughs which are completed by street inlet. In some of the street internodes, drainage tends to less maintained and much rubbish piles in the surrounding stripes. Thus, this condition causes gutters to become narrowed and it will disrupt the function of strips especially in the rainy season.

c. Majalaya Sub District.

Generally, waste in the Majalaya sub district comes from industry and household activity. This is because most people in the Majalaya sub district still do not have septic tanks, so domestic waste is disposed directly into the nearest river without going through a septic tank. Majalaya sub district has three types of drainage: primary, secondary and tertiary. Primary drainage is existing rivers in surrounding city with average condition. Thus, secondary and tertiary drainage is gutters along the street. The condition of secondary and tertiary drainage has generally damaged which caused by rubbish piled or sludge. There are four rivers that are used as primary drainage: Citarum, Cipadaulun, Cipeujeuh, and Cibotor Rivers. In addition, waterways of irrigation are used for drainage system in this area. Majalaya sub district until 2001 has five irrigation check dams which are located in Citarum River (three irrigation check dams) and Cisunggalah River (two irrigation check dams).

d. Rancaekek Sub District

Domestic wastewater disposal infrastructure in Rancaekek sub district consists of individual and communal infrastructure with on-site and off-site systems. Individual on-site system consists of family toilet with or without septic tank, whereas communal on-site is communal sanitation facility and communal toilet. The off-site infrastructure is pipe system made of SBS. Sludge from on-site systems is drained with vacuum truck and disposed to communal fecal sludge treatment units together with wastewater which was collected and disposed to Majalaya Fecal Sludge Treatment Installation in Cibeet. The domestic wastewater service scope is 88 %. The existing drainage system in Rancaekek sub district generally is still made predominantly of ground pipes. The rivers which function as primary drainage are Citarik and Cikeruh Rivers. Thus, existing drainage system in Rancaekek sub district can be clustered into a macro drainage system which consists of receiver pipes like the Cikeruh River that serves a wider area, and micro drainage which consists of some artificial pipes with local service scale. The current condition showed that existing drainage is in poor condition, and mentioned that drainage is no longer able to load water in normal capacity as consequence of insufficient carrying capacity drainage rate caused by shallow sludge and rubbish in the drain area. Based on data of Water Management Agency, Rancaekek sub district is including as flood area and ± 7.3% is flood area. Average depth of flooding is 0.3 – 0.5 m with average flooded duration is between 1 – 2 hour.

(4) Cimahi City

The wastewater flow pattern in Cimahi City currently uses the Cimahi River Flow and its tributaries as primary drain and some of water drains, whereas existing water drain (secondary drainage) currently is of an unpatterned condition. The existing condition of wastewater drain in Cimahi City is beginning to become damaged and because of sludge and rubbish which caused the carrying capacity from drain to become reduced. In some places, the existing drainage has changed its function and use for land use.

(5) Sumedang Regency

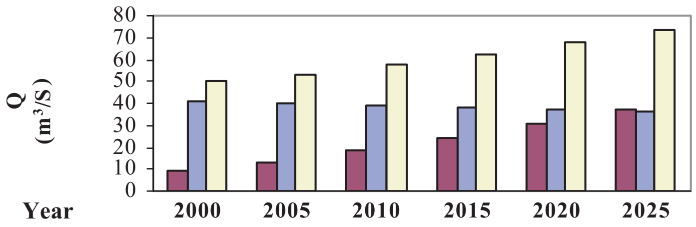
Sumedang Regency, especially districts which includes in Bandung Metropolitan like Jatinangor, Tanjungsari and Cimanggung, their drainage infrastructure availability is still limited. Only Tanjungsari and Jatinagor District have drainage, whereas Cimanggung District has no drainage system. The final destinations of sewage drainage of Tanjungsari City are Cisamangka and Cipeles River. Drainage infrastructure in Jatinangor City is maintained by Public Works of Sumedang Regency, a branch of Public Works of Tanjungsari.

2.8 Water Demand

In the Water Resources Development Plan of Metropolitan Bandung has indentified how much demand of water which have to be supplied in 2005 to 2025. It estimates that there are two possible scenarios, namely:

i. Rapid water demand growth based on tendency and implicit assumption that the economic condition would enhance and the government could optimize economic potency that in turn would hasten the economic growth pace.
ii. Lower water demand scenario because of slow economic growth.

Various issues have been considered in the development plan. To mention a few, there are the issues of ineffective wastewater treatment both for industry and for domestic, over-exploitation of groundwater that results in groundwater depletion, especially in areas with clustered industries. Estimation for water scarcity in the future requires special attention on conservation and water demand management, including minimization of water leakage, public awareness campaigns, and improvement of tariff/tax system that can support conservation efforts. One point of the Water Resources Development Plan for Citarum River Basin is that the water demand for domestic, urban, and industry is not described in detail, which makes it difficult to estimate water allotment for each sector. However, the appendix mentioned that water demand estimation for each sector was determined based on a target of number of population served with a tap water system. The interpretation below is based on current conditions and several assumptions of what might happen between 2005 and 2025. Estimates for agricultural water demand decreasing is at around 1-2 % /year due to population pressure and land use change, while the increase in water demand for the industrial sector is estimated to be around 0.5-1 % /year.
The figures above presents water demand scenarios for various sectors, i.e. domestic, urban (flushing, public hydrant),



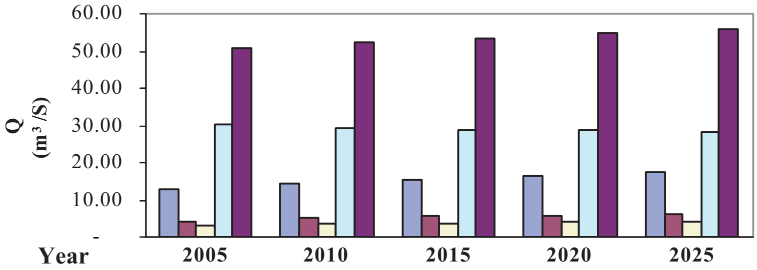
Year	2000	2005	2010	2015	2020	2025
🟥 Demand for Domestic, Urban and Industry	9.323	13.085	19.041	24.604	31.027	37.083
🟦 Demand for Agriculture	40.868	39.969	39.07	38.171	37.221	36.372
☐ Total	50.191	53.054	58.111	62.775	68.248	73.455

Figure 3. Water Demand Projection

Source: Water Resources Development Plan for Citarum River Basin, 2002

industry, and total requirement for agriculture. Total demand for the three main sectors, domestic, industry, and urban use, have similar increasing tendencies due to economic growth in the area. In the early years of planning (2000) it was estimated that total demand for the three sectors will achieve 9.32 m^3/s. In the second period of planning, total demand for the three sectors was estimated to be 13.1 m^3/s. Similar trends will continue to apply in planning period of 2010, 2015, 2020 and 2025. From the projections, water demand for the three sectors is estimated to be around 37.1 m^3/s.

Meanwhile, water demand estimation for agricultural sector will have a different tendency from the previous three sectors. One of the causes is assumption of land use change. Generally, there will be 0.18 m^3/s decrease in water demand for the agriculture sector during 25 years of planning period. In the year 2000, water demand from agricultural sector is estimated to be 40.87 m^3/s and decreasing, so that by the end of the planning period the number will become 37.22 - 36.37 m^3/s. From figure 1 we can see that by the end of the planning period (2025) the water demand from the agricultural sector will be equal to total water demand from the other three sectors. Scenario of total water demand in the early planning period (2000-2005) will range from 50 – 53 m^3/s. Generally, water demand increase will achieve total of 46,35 m^3/s or equal to 46.35% from early planning scenario in year 2000. By the end of planning period (2025), total water demand in the river basin will achieve almost 73.5 m^3/s. As mentioned previously, absence of detailed information about water demand for each sector makes it difficult to measure target achievement. Another analysis was conducted to calculate portion of water demand for each sector. To calculate water demand for the domestic sector, statistical approach using latest data of population growth from Board of Statistics was applied. Figure 4 shows that the water demand for domestic sector in year 2005 was 13.03 m^3/s. In 2010 the number is estimated to be 14.13 m^3/s, and by the end of planning period the number will increase to 17.41 m^3/s.



Year	2005	2010	2015	2020	2025
■ Domestic Use	13.03	14.13	15.22	16.32	17.41
■ Industry Use	4.25	5.22	5.49	5.76	6.05
□ Others Use	3.26	3.53	3.81	4.08	4.35
□ Agiculture Use	30.30	29.34	28.90	28.46	28.03
■ Total	50.85	52.22	53.41	54.62	55.85

Figure 4. Re-analysis Water Need 2005-2025

On the other hand, water demand to supply 10 industrial clusters (Padalarang, Cimahi, Batujajar, Cimahi Selatan, Ujung Berung, Rancaekek, Majalaya, Dayeuhkolot, Banjaran) in year 2005 was 4.23 m^3/s. Based on estimation of industrial growth by 1% /year, for the planning period of 2020-2025 total water demand for the industrial sector will achieve 5.76 – 6.05 m^3/s. By the year 2025, water demand from urban sector (flushing, public hydrant) will increase to 4.35 m^3/s. From a re-analysis, total water demand for the three sectors by 2025 is almost 30 m^3/s. Water demand from the agricultural sector based on re-analysis will fall in the range of 30.30 m^3/s in year 2005, becomes 29.34 m^3/s in 2010, and continually decreasing to 28.03 m^3/s by the end of the planning period. Total water demand from all sectors in Bandung Metropolitan area is estimated to reach 55.85 m^3/s by the year 2025.

3. Issues and Discussion on Groundwater Management

Groundwater extraction has been well recorded by the Direktorat Geology Tata Lingkungan dan Kawasan Pertambangan (the Directorate of Environmental and Geology) since 1900. Groundwater extraction from 1900 to 1990's showed an increasing trend and achieved its peak in 1997. It was strongly expected due to economical crisis which hit this area. Groundwater use by industry went down significantly in 1997. After recovery, the trend of groundwater abstraction tended to increase back toward the level or previous usage. The abstraction trend of groundwater usage can be seen in this following figure 5.

Nearly 50% of textile processing plants include immersion process which requires great amounts of water. Many of them are located in areas that have no water supply infrastructure. Thus, groundwater becomes a cheap and effective solution for operating the factory. In 1993, groundwater use for the industrial sector reached almost 59.55 % of total water requirement, increasing to 66.34 % in 1995 and decreasing a bit in 1996, almost 59.60 % from the total amount of water required. The economic crisis took place in Indonesia in 1997, including West Java Province, had a significant impact on groundwater abstraction, as shown in following figure 6. In 1999, groundwater usage for industry decreased to 57.20 %, and went up into approximately 57.84 % in 2000. The prediction is that until 2004, groundwater usage will continue to increase, reaching almost 70 % of the contribution of total water required by the industrial sector in the Bandung Basin, as until now the water works system covered less that 2% of total water needs.

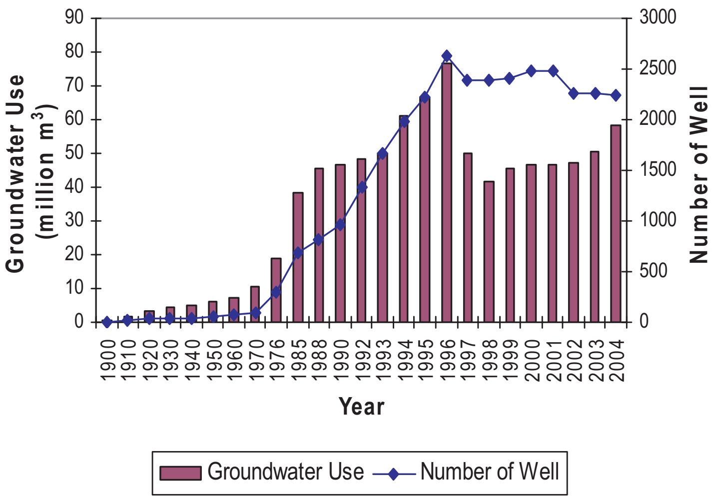
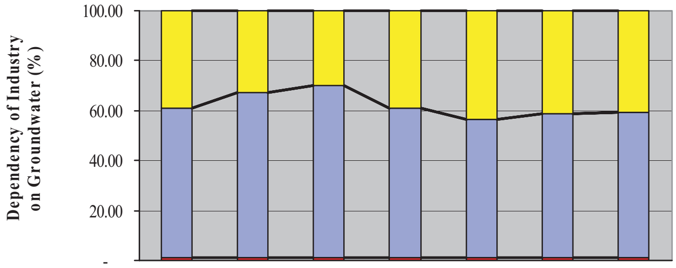


Figure 5. Numbers of Boreholes vs. Abstraction Period 1900 – 2004

Source: Based on Monitoring Data from the Directorate of Environmental Geology 1990 – 2001 and West Java of Mining Agency (2001-2004)



Year	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

Figure 6. Percentage Dependency Groundwater Use at Industry Activities

This following table describes the amount of groundwater extraction from 1993 to 2000. Recorded Data in 1993 groundwater use for domestic purpose was 104,218,377 m^3 and tending to increase, though during the period of 1997 -1998 it rather slowed down. In 1995, domestic groundwater use reached 107,239,387 m^3 and went down to become 95,088,048 m^3 in 1998. It was estimated that there would be a decrease in water consumption caused by economical crisis, and that many residents would decrease their consumption. But for the next year the groundwater domestic use increased back over 134,634,849 m^3 in 2000.

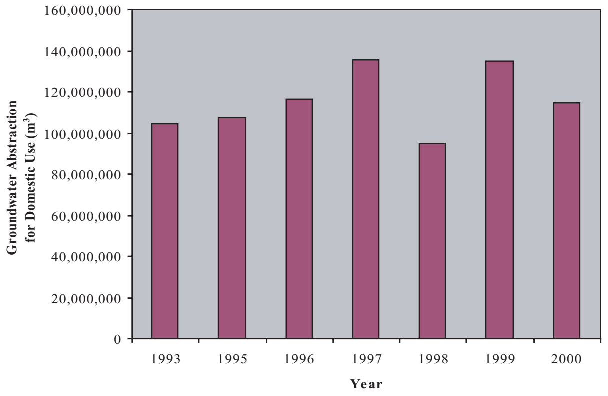


Figure 7. Groundwater Abstraction for Domestic Use 1993 – 2000

3.1 Associated Groundwater Problems

(1) Water Table Depletion

According to data from monitoring wells in some periods of years, the static groundwater table in Bandung basin has changed significantly, from a positive artesian (flowing) to a negative artesian (pumping). For example, positive arthesis distinguished in Dayeuhkolot-Bojongsoang area was +4.0 m above ground level in 1920, but in 1960 the water table depleting to +3.9 m above ground level. In mid 1970's, groundwater table has changed to -2 m below ground level and decreasing to 40 – 80 m below ground level 1990. The same phenomenon occurs in one of area in Cimahi City area, in a well that has been monitored since 1920, which initially had positive arthesis with pressure +19 m. In the mid 1950's, the pressure decreased and in the early 1980's the pressure reduced and went into a pumping phase with pressure -3 m under ground level. In 1985, the groundwater table has reached -10 m under ground level, and in 1995, the groundwater table perceived penetrating into - 40 m under ground level (Harnadi and Iskandar 1993, 1998; Suyono 1990; Priowijanto and Gatot 1995; Agus and Iskandar 2000).

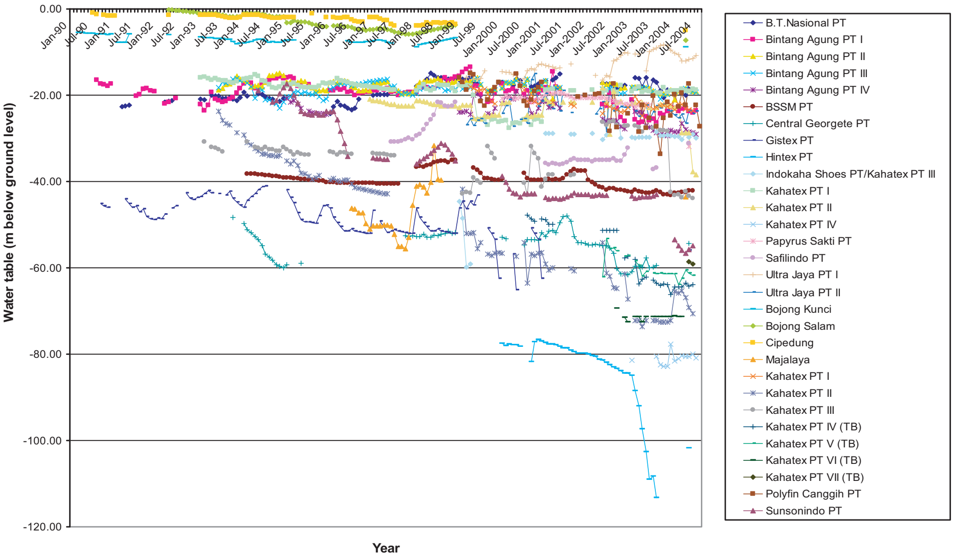


Figure 8. Water Table Depletion in Several Monitoring Well

Source: Satrio, Directorate of Environmental Geology 1990-2004

The groundwater level was also monitored by Automatic Water Table Recorder (AWLR) at 30 monitoring wells in the study area. The Directorate of Environmental and Geology (Satrio, DEG 2004) identified the change of groundwater table until July 2004. Areas with deepest depletion of static groundwater level forming cone of depression are Cijerah with over

20 m depletion during 1997-2004 period, Cimanggung with more than 60 m depletion over the past decade (1994-2004).

In Rancaekek, measured at PT. Kahatex deep well, the groundwater has depleted more than 60 m throughout the past decade, and in Leuwigajah Industrial Estate, the depletion reaches 40 m during 1994-2004. Moreover, groundwater depletion also affects WSE deep wells. There were 32 deep wells along the rail and it was effecting the decreasing of WSE water extraction, from 550 l/s in 1982-1983 to 115 l/s in 2004.

From the empirical data above, groundwater table in middle aquifer ranges from 0.92-84.24 meter and deep aquifer ranges from 62,83 – 85,76 m below ground level. Excessive groundwater consumption, especially in dense industrial clusters, manifestly has the negative effect of significant groundwater depletion. Meanwhile the result of the monitoring period from July 2004 until July 1995 concluded that the rate of groundwater depletion in middle aquifer is about 0.12 - 8.76 m/year and in deep aquifer is about 1.44-12.48 m/year.

(2) Land Subsidence Symptom

Although many factors causing of land subsidence in Metropolitan Bandung, yet excessive groundwater extraction for industry, trading, and domestic uses are the main factors. Land subsidence very significantly happened, particularly with deep aquifer. The source of groundwater coming from recharge area which is located quite far away and the flowing into discharge area need may take years time to replenish. Land subsidence of shallow aquifer was not as terrible as with deep aquifer. That could be because groundwater is more replaced by surrounding surface water, particularly in the wet season. Drastic land subsidence happened since 1980's in line with the increase of industrial and settlement activities. Therefore, the significant problem of land subsidence happened in industrial area such as Leuwigajah, Batujajar, around Mohamad Toha Street, Dayeuhkolot, Rancaekek-Cicalengka, Ujungberung, Cicaheum, and Kiaracondong. At settlements and housing, decreasing happened at shallow groundwater level, seen by the difficulty residents encountered in attempting to get groundwater from their dug well.

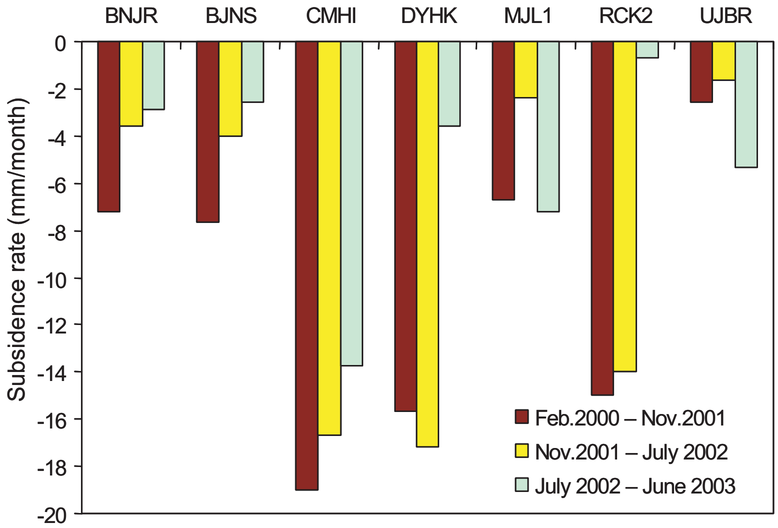


Figure 9. Various of Land Subsidence Average Temporary in Several Area

Source: Abidin et. all, 2003

Note: BNJR, BJNS, CMHI, DYHK, MJL 1, RCK, UJBR, mean Banjaran, Bojong soang, Cimahi, Dayeuhkolot, Majalaya 1, Rancaekek 2, Ujung berung, respectively.

Measurement of land subsidence periodically conducted using Global Positioning System (GPS) reveals that land subsidence for several location can achieve 20 mm/month or equivalent 24 cm/year particularly at several area which are entering a critical zone, including Cimahi, Rancaekek and Dayeuhkolot (Abidin et. all, 2003).

One of the main causes of groundwater depletion is change of land cover, which may lead to changes in the hydrological cycle, especially when the conversion occurs in the recharge area. The Directorate of Environmental and Geology (DTLGKP and BPDPJB 1996) categorized 21 sites of recharge areas in the Bandung Basin as follows: 60,881.31 ha

(26%) as "main recharge areas," 67,911.89 ha (29%) as "inconsequential water recharges areas" and 56,069.66 ha (24%) as "additional recharge area." The "discharge area" covers 38,970.4 ha (16.6%), as shown in following figure. General recharge mechanism of shallow aquifer in Bandung basin is a direct process whether it comes naturally or is caused by human, and it takes place at once or lately in weekly range. Meanwhile, recharge process to middle aquifer and deep aquifer happened directly or indirectly. Direct process happens in the main recharge area and indirect process happens in almost every watershed area. This condition happens because isometric height from deep groundwater in position under shallow groundwater phreatic height. It means that recharging process takes place firstly to shallow aquifers and continues to middle and deep aquifer through the leak.

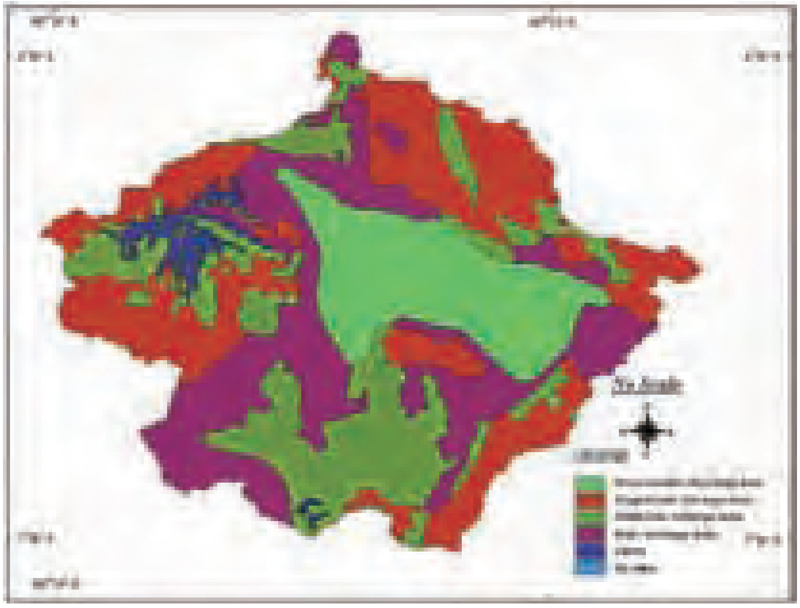


Figure 10. Categories of Water Recharge Areas in The Bandung Basin
Source: DTLGKP and BPDPJB 1996.

An overlay of land-cover patterns in 1983, 1993, and 2002 in the Upper Citarum Watershed is shown in the table, in which the following two main patterns in land-use change can be observed: (1) a dramatic increase of open area, bushes, and urban and suburban area, and (2) a decreasing trend of rice fields, forest, and grass/open fields. Based on these results, it is obvious that the main change in land-cover pattern is an overall decrease in vegetated land to non-vegetated/built areas and open areas.

Table 3. Types of Land Cover in the Upper Citarum River Basin, 1983, 1993, and 2002

Land-use type	1983		1993		2002	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Lake	253,44	0.11	4,223.52	1.80	3,202.56	1.37
Open space	15,806.88	6.75	23,997.60	10.25	29,325.60	12.53
Meadow	6,474.24	2.77	3,620.16	1.55	2,105.28	0.90
Grassland	30,510.72	13.03	16,852.32	7.20	7,866.72	3.36
Rice field	52,702.56	22.51	44,575.20	19.04	23,510.88	10.05
Forest	85,138.56	36.36	69,454.08	29.66	39,150.72	16.73
Bush	33,363.36	14.25	48,470.40	20.70	93,638.88	40.01
Plantation	1,810.08	0.77	2,731.68	1.17	3,306.24	1.41
Urban	5,117.76	2.19	10,499.04	4.48	17,038.08	7.28
Suburban	2,473.92	1.06	5,156.64	2.20	6,304.32	2.69
Public facility	136.80	0.06	982.08	0.42	1,869.12	0.80
Industry	355.68	0.15	2,553.12	1.09	3,444.48	1.47
Cloud	2.88	0.001	1,022.40	0.44	3,278.88	1.40
Total	**234,146.88**	**100.00**	**234,138.24**	**100.00**	**234,041.76**	**100.00**

Source: Wangsaatmaja 2004.

(3) Groundwater Quality Deterioration

The result of groundwater quality monitoring conducted in 2004 shows that total coliform levels of 76 % of all samples (19 of 25 samples) exceed the standard of 1000 MPN/100ml. Fecal coliform of 25 sample's location is indicated that 18 among (72 %) are over standard stated for class 1, namely 100 MPN/100 ml. This shows that treatment of water for drinking purpose, in particular at those locations above need to be done before that water will be consumed domestically. If considering based on sampling locations, locations with high number of coliform bacteria which exceed water standard are high-dense residential area, such as settlement area. Also, some of them represent industrial area in Bandung Basin at the present time. The result of laboratory to 50 tested samples taken at locations in the Bandung Basin in 2005 show that 78 % of those samples did not comply with standards, and 70 % exceeded fecal coliform standard. Only one of the sampling point did not show presence of coliform bacteria. It was because the well was quite deep. In fact, almost 90 % of all samples are relatively close between dug well and septic tank. According to our standards, the distance between a well and septic tank should be over 10 m. It can be predicted that all dug wells have been contaminated by domestic waste water, such as human faces. Another reason why the number of coliform is above the standard in those areas is that the sanitation facility around the sampling points were unclean and not maintained.

3.2 Policy Responses

(1) Centralized period (1945–1998)

The following section presents the major policies related to groundwater management instituted during Indonesia's centralized period.

The National Act of the Indonesian Republic, 1945 (UUD 1945), 2nd Amendment, 2000, stated very clearly that natural resources, including water resources, are considered a public good that must be managed fairly and used for the benefit of the Indonesian people.

Act Number 11, 1974, Watering, article 2, stated that water, which includes groundwater (articles 3, 4, and 5), is a public good that has a social function and must be optimally used for the well being of people. Yet, in contrast to surface water, other institutions were put in charge of managing groundwater. As stated in article 5, the authority for water management was divided between two bodies, i.e., all water except groundwater was the responsibility of Menteri Pengairan (the Minister of Watering), while groundwater became the task of the Mining Department/Minister of Mining, as further detailed by the central government through the Government Law on Water Arrangement. According to article 5, Act Number 11/1974, the Minister of Watering was responsible for coordination of all efforts in planning, technical planning, monitoring, usage, maintenance, and protection of water and/or water resources, taking into consideration the interests of related departments and institutions. Section (2) of the article states that administration arrangement of groundwater and hot springs as mineral and power sources was outside the authority of the Minister of Watering. In 2004, Act 11/1974 was revised under Water Resource Act, Number 7, 2004 (discussed further in the next section on the decentralized period).

In an effort to conserve groundwater in the Bandung Basin, the governor of West Java in 1982 issued Governor Decree Number 181.1/SK.1624-Bapp/82, a land-use policy arrangement for the core of the Bandung metropolitan area, which included an administrative boundary arrangement, land-use policy, and efforts and guidance for land development. Simultaneous to these efforts, the central government, through Direktorat Geologi Tata Lingkungan (DGTLKP) (the Directorate of Environmental and Geology), conducted research on groundwater and began monitoring the static groundwater level in their monitored wells. In the mid-1990s, the directorate issued the Groundwater Zoning Recommendation to reduce the rate of groundwater depletion. It became the official guide for related parties in terms of groundwater usage, including industries that mostly use groundwater as their water source for production processes. Formal operational and implementation plans were set out in the Minister of Mining and Energy Rule Number 02P/101/M.PE/1994, Minister of Mining and Energy Decree Number 1945.K/102/M.PE/1995 on Guidance for Groundwater Management in the Second State Government, and DJG Decree Number 005.K/10/DDJG/1995 on the Technical Guidance for Groundwater Management. Referring to recommendations by the Directorate of Geology and Environmental, the West Java provincial government issued West Java Provincial Rule, Number 9, 1995, on Groundwater and Surface Water Monitoring, which basically included the following items:

i. Groundwater abstraction must be conducted by an operational body that possesses a groundwater abstraction license or by a government institution with devices accredited by the general director of Geology and Mineral Resources, the national institution which is under the Ministry of Mining and Energy.
ii. Construction of a groundwater abstraction installation must be based on technical guidance from the Public Works Agency or a technical institution of water management in a related river watershed. It states implicitly that the groundwater abstraction mechanism requires the active involvement of the Direktorat Geologi Tata Lingkungan Kawasan Pertambangan (DGTLKP) (the Directorat of Environmental and Geology) and Dinas Pertambangan Provinsi Jawa Barat (DPPJB) (the Mining Agency of West Java Province).

Simultaneous to issuance of the provincial government's rule, the local government issued Bandung Regency Government Rule Number 43/1995 on Groundwater Control License, which contained similar content.

With the establishment of Act Number 18/1997 on Local Tax and Retribution, the tax on surface water and groundwater usage was classified as a second[3] state government tax. In 1998, the city of Bandung issued Bandung City Government Rule Number 3, 1998, on Groundwater and Surface Water Usage Tax. The calculation of tax was described in chapter III, articles 5 and 6, of the rule. Article 5 stated the following: (1) tax is based on water provision value; (2) water provision value is calculated by multiplying the water volume by the basic water price; (3) the basic water price is calculated by considering the type of water source, its location, groundwater abstraction, water quality, area of water usage, season of water abstraction, and environmental degradation due to water abstraction; (4) the basic water price is determined periodically by the mayor with approval from the Bandung City Legislation Board; and (5) the water provision value is also determined by the mayor. Article 6 of the act determined that the tax charged would be a maximum rate of 20%.

(2) Decentralized Period (1998–)

The interesting point in the decentralized period began in Indonesia in 1999 when Act Number 22/1999 on Local Government was issued (it was revised by Act Number 32/2004). This act handed governing authority (including natural resources management) from the central government to local governments, and it was to be accompanied by funding, infrastructure, and human resources. Facts show, however, that not all of these elements have been entrusted by the central government to local governments. The consequence of local governments being forced to generate their own revenues was a massive exploitation and poor management of resources, especially trans-boundary assets.

Act Number 34, 2000, of Amendment of Indonesian Republic Act, Number 18, 1997, changed several taxation mechanisms. It stated that local governments are given the authority for taxing groundwater abstraction, while, according to Act 34/2000, article 2, that kind of taxation authority is part of provincial government revenues. To implement the act, the Provincial Government Rule of Regional Tax was issued. The Tax on Surface Water and Groundwater Usage and Abstraction can be found in chapter 5, articles 33, 34, 35, and 36, which set the tax for groundwater abstraction at 20%.

In 2000 the Minister of Energy and Mineral Resources issued Decree Number 1451 K/10/MEM/2000, appendix 1, Technical Guidance For Groundwater Potency Evaluation, and appendix 2, Technical Guidance for Groundwater Planning and Usage, as reference material and a source of information on groundwater potential, with the specific aim of integrating groundwater management among different local governments. According to Minister of Energy and Mineral Resource Decree Number 716.K/40/MEM 2003 on Groundwater Basin in Java and Madura Island, the groundwater basin in Bandung Basin is divided into three basic aquifers, namely, the Lembang, Batujajar, and Bandung-Soreang basins.

In 2001, the West Java provincial government issued Provincial Regulation Number 16/2001 on Groundwater Management. Chapter 2 of the regulation, Planning for Groundwater Usage, stated that planning activities must be conducted as a basic condition for proper groundwater management in any given groundwater basin. In article 5, sections 1 and 2, it is stated that groundwater is prioritized for domestic use, and that other uses are allowed under certain conditions. In chapter 6, Licensing Facilitation, article 6, it states that groundwater abstraction activities can

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[3] The second tax is taken by provincial or district level. The ground water and surface water tax is among them

be conducted only with a license from the relevant mayor or regent. Meanwhile, groundwater abstraction in trans-boundary areas has to follow several technical conditions set by the related agency, the Mining Agency of West Java, except for those abstracting less than 100 cubic meters per month (m^3/month). Article 12 mentions that monitoring and enforcement activities are done by the Mining Agency in cooperation with related institutions at the city or regency government level, which includes the following: (a) the location of the groundwater abstraction point, (b) a technical construction and pumping test, (c) limitation of groundwater discharge abstraction, (d) technical arrangements and installing a monitoring device, (e) data collection of groundwater abstraction, (f) taping water technical, and (g) hydrology analysis.

To support Provincial Regulation Number 16, 2000, the West Java Governor Decree Number 23/2002 on Implementation Guidance for Provincial Legislation Law Number 16/2000 was issued in 2002. It is clearly stated in article 2 of the decree that the governor has the authority and responsibility for groundwater management in trans-boundary areas. Article 8, sections 1 and 2, lists the following technical information required from applicants for a groundwater abstraction license: (a) location of the abstraction point, (b) distance between the planned point and the nearest point, (c) the number of points the applicant possesses, (d) name of the registered abstraction contractor, (e) depth of the aquifer, (f) the maximum discharge, (g) pump depth and capacity, and (h) details of bore hole construction. Included under the last item are the following: (i) depth of the well, (ii) diameter and length of the main pipe, (iii) diameter and length of the strainer pipe, (iv) diameter and length of the head pipe, (v) diameter and length of the piezometer pipe (for measuring the elevation of the water table), (vi) location of the gravel mantel, (vii) location of the cement layer, and (viii) location of the piezometer pipe. Article 9 of this regulation states that applicants must provide a 1:10,000 layout map showing the abstraction point and a 1:25,000 map for well coordination. Hydrological analysis is compulsory to gain information for zoning the groundwater abstraction point as being in a critical, vulnerable, or safe zone.

Bandung City Regulation Number 8/2002 issued by the city of Bandung is similar to the provincial regulation. In article 6, groundwater abstraction for domestic use below a withdrawal of 100 m^3/month with depth ranges from 40–60 m do not need a license for abstraction, a recharge well, or a monitoring well.

West Java Governor Decree Number 29/2003 was issued as the basis for calculating the groundwater usage tax, which considers three main components: natural resources, conservation, and raw water price.

3.3 Overview Effectiveness and Deficiencies of the Policies

Basically there have been several regulations trying to improve and protect groundwater management in Metropolitan Bandung since 1980's. But in fact, deficiencies are still happening and rather difficult to implement issued regulation both by provincial and local government. For instance, the idea of limiting excessive groundwater abstraction through stopping a new license and zoning for critical area is also difficult to implement. The following table explains the effectiveness and deficiencies of existing measures.

Table 4. List Measure and Effectiveness Policy in Metropolitan Bandung

Measures	Date Implemented	Effectiveness	Deficiencies
Using of License	1974	N/A	Unregistered well particularly by industry use still exists
Zoning Area (1) Critical Area, (2) Vulnerable Area, (3) Safe Area	1994	N/A	Water table depletion in critical areas is still happening
Groundwater Use Charge	1974	N/A	No charge for domestic use due to that this subject is public goods
Abandonment of Groundwater Wells by WSE	1990	N/A	Groundwater source is still used by WSE for certain area
Plan of Industry Relocation	1990		High Cost
Groundwater License Requirement Based on Technical Aspect: (1) Deep and Length of Strainer, (2) Discharge of Pipe Diameter, (3) Power of Pumping Equipment, (4) Deep of Well, (5) Piezometer Pipe Diameter, (6) Deep of Aquifer Extracted	1995	Effective	
Limiting Groundwater Abstraction	1995		Water table depletion is continuing
Groundwater Charge	1995	Effective for industry 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 Area	2000		Water table depletion is continuing
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 industry use but not effective for domestic use	No charge for domestic use
Establish Monitoring Well			Water table depletion is continuing
Introduce Recycle and Reuse Technology	2000	Not effective	No incentive for industry which has done
Reporting of Groundwater Extraction		Effective for knowing how much groundwater amount extracted by industry use	
Introduce Recharge Well for Both Domestic and Industry Use Particularly in Conservation Area	1995	N/A	Only 5 % domestic residing in the conservation area complied with this regulation
Groundwater Data and Information System	2002		Not up-dated
Closing Unregistered Well		Effective	

Source: Stakeholders Meeting' Bandung Case in January 2006 under SWMP

4. Issues and Discussion on Alternative Water Resources and Water Recycle Program

4.1 Maximizing of Surface Water Resources

Figure 11 below depicts more clearly water balance condition in Metropolitan Bandung. In normal condition all tributary and the main rivers (Citarum River) have water availability around 806.71 million m^3/year. The water surface potency in minimum condition is able only to provide 237.46 million m^3/year, meanwhile in maximum condition the water potency will be 1,750 million m^3/year. Those things in dry season have caused in several areas to undergo deficit of water in terms of fulfilling the needs. Phenomenon of water scarcity is a common situation and tends to increase recently. Based on total necessity which has to be provide for agriculture (825 million m^3/year), raw water for Water Supply Enterprise

(WSE) (76.8 million m^3/year) and industry need (135 million m^3/year) at least are needed 1,036 million m^3/year to fulfil those activities.

From the identification result of Water Resources Development of Public Works in 1996 it is known that at least 25 reservoir locations have the potential to be further developed and many locations have been investigated. Annual volume of those reservoirs are calculated based on how much water availability and capacity by analyzing input – output of flow rate in monthly basis.

Efforts to fulfil water demand in Bandung Metropolitan area is emphasized on maximizing surface water resources potency. This scheme shows that at least eight small dams will be constructed to supply raw water for household, industrial and urban sector demand. Raw water from Saguling Dam is another alterative to be used in the year 2015. In the meanwhile, groundwater usage will be allocated for areas with difficult access to piping system in Bandung Metropolitan. The following table shows us that surface water development plant through building several reservoir in upper area can significantly increase the amount of water in that area. At least, around 331.96 million m^3/year can be provided by those reservoirs. This grand design to maximize surface water resources have not been constructed yet so far because of burden on the budget. The resulting amount of surface water resources added by development with engineering can be viewed in table 4 below.

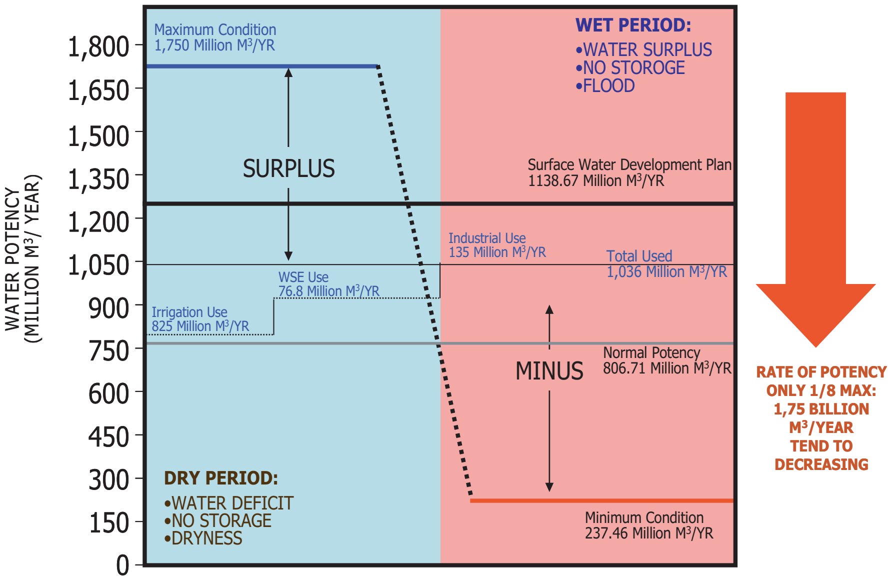

Figure 11. Surface Water Condition in Metropolitan Bandung

Table 5. Surface Water Resources Development With Enginering

Sub River Stream Area	Water Available	Potency (million m^3)		Treatment Capacity (million m^3/year)	Potency With Engineering	Location of Reservoir
		Without Engineering*	Engineering**			
Cimahi	32.75	10.41	22.34	10.00	20.41	Paneungteung
Cibeureum	43.27	10.4	32.87	0.00	10.4	
Cikapundung	97.21	21.13	76.08	3.70	24.83	Cikawari
Cipamokolan	153.9	21.13	132.77	0.00	21.13	
Cikeruh	45.07	18.29	26.78	3.20	21.49	Cikuda
Citarik	27.68	27.68	0.00	0.00	27.68	
Citarum Hulu	75.92	35.00	40.92	1.40	36.4	Cipariuk
Cisarea	0.00	0.00	0.00	3.35	3.35	Peuris Hilir
Cisangkuy	183.91	52.98	130.93	9.50	62.48	Talun
Ciwidey	144.00	38.79	105.21	8.00	46.79	Ciwideuy
Daerah Banjir				50.00	50.00	Tegalluar
Total	**806.71**	**239.81**	**572.90**	**95.15**	**331.9*** **	

Source: Regional Office of Public Works, 1996

* *Water which has no been optimized*

** *Water potency could be optimized by engineering approach*

*** *The total water which has no been optimized by engineering approach (construct reservoir/small lake)*

4.2 Water Recycle Program

As has been explained in the previous facts, it has been discovered that the biggest groundwater user is the industrial sector. Almost all (57.84 %) the water requirements in this sector are supplied from groundwater sources and only 2 % are fulfilled by the water piping network. This process has occurred continuously, and the result is a continuing worsening in groundwater level depletion. In the Metropolitan Bandung water development plan it mentioned that two structural approaches shall be conducted focusing on perpetual groundwater management. In the bottom line, those two approaches could be divided into groundwater usage limitation on 2.4 m^3/s since 2003 and providing alternative water sources to the industrial sector that shall be started in 2005.

Structural effort on groundwater usage limitation is strengthened by best case scenario that would be implemented as studied in groundwater utilization plan (Mining Agency, 2002). This scenario is intended to alter several critical zones, and is expected to improve the situation and turn vulnerable sectors into safe zones. To achieve it, reducing groundwater abstraction is conducted in difficult and critical zones and increased groundwater abstraction to a certain limit in safe zones.

Simulation results show that in 2013, critical zones would become extremely problematic areas by 100% or decreased for 222 km^2 total areas than the current condition. Discharge abstraction zone shall be implemented to achieve maximum target from this determined scenario. Discharge zone for only 300-400 $m^3/km^2/day$ is implemented to critical zones and no new groundwater abstraction permit would be issued for industrial zone. Therefore this effort would reach the target in 2013. Whereas 1400-2000 $m^3/km^2/day$ discharge zone would be implemented in safe zone or central urban activities areas and focused in groundwater utilization for domestic necessity.

An important question emerging is how the industrial sector activity could develop its production processes, including participation in actively reducing of dependence on groundwater utilization. The water resources development plan states that one effort that should be conducted by industry is to introduce cleaner technology concepts including implementing and utilizing water recycling processes within the industrial sites.

It is uncertain when the water recycling concept was started in Metropolitan Bandung. From a preliminary survey conducted by direct interview method, however, resulted in that at least from several recent years industrial sector has initiated this recycling program. Their main motivation is concerning their difficulties to fulfil the water requirements either from groundwater or surface water. Allowing no new abstraction permits has become an obstacle when the production capacity is intended to be increased. Purchasing of water from individual supplier is more expensive. Another motivation is that water recycling is indirectly economical, and more profit could be obtained than by purchasing water from individual suppliers.

One of the recycling efforts in industry originated from wastewater produced by production process. Total of wastewater produced by 194 textile industries (spread out) is noted at least 2.6 m^3/s (Wangsaatmaja, 2004). If it could be exploited maximally, the target is to decide how much recycled wastewater rate that would be approved in the next water recycling meeting, at least it could be a potency of raw water supply for production process in industries. As an illustration, if this effort succeeds and reaches the target, 50% of wastewater will be recycled, hence raw water necessary for industries that is around 1.3 m^3/s can be supplied from this scheme.

There are two options which could be considered in application of recycling program in industrial sector. The first option is to conduct recycling of water off-site or else integrated into the industrial area. This option guarantees that wastewater recycling program is conducted consistently and constantly, and runs in a wide scale. The weakness of this option is the requirement of higher investment, considering that its implementation has preconditions that must be fulfilled.

The main precondition to apply this option is having a prepared integrated wastewater management system and operated in industrial area scale with relatively wide area necessary. The only integrated wastewater management that has been built since 1985 is located in Cisirung, Kabupaten Bandung, with an operation capacity of 0.175 m^3/s. This infrastructure is built from the Central Government fund and the second stage of development is from Central Government. At this moment, the plant is able to treat wastewater coming from 27 industries (26 textile industries and 1 food industry). Whereas, an option of on-site industrial wastewater recycling system is relatively easier and could be applied immediately in industries, however, the option of on-site water recycling also has weakness because it only depends on the willingness of the industrial parties themselves and is voluntary. Economic calculation is mostly considered whether option to conduct water recycle could give economic benefit to the company.

From all industries in Metropolitan Bandung, it has not been listed exactly how many industries already conduct a recycling program. For temporary example, from around 400 industries located and spread out in Cimahi City, only about 10 industries identified applying water recycling program in their production process. Result of preliminary survey conducted in several industrial locations located in Cimahi cluster shows an interesting fact related to recycling implementation. Part of it already mentioned in the previous chapter, is that economic motivation is the main reason for implementation of this program

Arising from the difficulty of several industrial parties in water demand fulfilment for production process, especially in dry season, they initiated finding alternative substitute for groundwater by buying from a third party that provides this service. On the other hand, the proposed price from this individual water provider is 20,000.00 -25,000.00 IDR/m^3, while maximum groundwater tax that is burdened for usage above 5000m^3 is around 3,318 IDR/m^3, while WSE tariff is around 4,725.00-9,600.00 IDR/m^3. If consideration of water source is based on price viability, so that option of using water for production process by buying from individual water provider is the most expensive option and inevitable, considering until this moment WSE service has not reached to this area. To know the perception of industry concerning the water recycling program in detail, in the table below is summarized the result of a questionnaire which was taken from 33 industries.

Table 6. Result of Water Recycle Program for Industry

Item Questioner	Result
Water demand	Clean Water is the main need for the industry to conduct their activities, more so in the textile industries. From the collecting data, we can conclude that most of the industries (41.2 %) need about 10,000 -< 30,000 m^3/month of clean water, and (29.4 %) need 30.000 – 50.000 m^3/month, while the others (17.6 %) need clean water up to 50,000m^3/month, and the remaining 4 industries (11.8 %) did not answer the question.
Industrial Water Use	The water demand are including all the industrial demands, which are production process, domestic activities in the industrial site, i.e. shower (bath), washes and rinses. Some industries need to supply clean water to the residential areas near the industrial site, for the geothermal electricity generator, etc., while (64.7 %) stated the main needs are for the production process, domestic industry activities, and other activities and (23.5 %) stated that the needs are for the production process and domestic only. The others (5.9 %) stated that the needs are for the production process only. The table of the Water Usage in the industry is shown in table below.
Water Resources	There is none of the industries that use the water from the Water Supply Enterprises (WSE). 47.1 % industries that use the groundwater with the surface water, or the groundwater with the rainfall, stated that the most used resources is the groundwater, so it can conclude that the groundwater is the most used water resources in Metropolitan Bandung
WSE service area	The reason that none of the industries use the water from the Water Supply Enterprises (WSE) is because of the low coverage of WSE service area (the supply does not reach the industry). From the 33 industries, there is only one industry that is reached by WSE. The rest of all (88.2 %) stated that they were not covered by the WSE service area, and 5 % did not answer the question.
Water Problem in Industry	Although the industries have the licenses to use several types of water resources, but the water resources availability does not optimally fulfil industrial activities demand. Some industries have problems from the water resources that they used. The main problems are the minimum capacity of the water resources (quantity), especially in the dry seasons (47.1 %), minimum number of the water sources (11.8 %), and two industry (5.9 %) is in quality (one of them are bottling drink water industry). The others did not answer or stated that they don't have any problems with their water resources.
Restriction of the groundwater usage for industries	Some of the industries that using groundwater agree if government established the regulation about the restriction of groundwater usage for industry. Percentage of industry which did not agreed with the proposed policy (46 %). Agreed as long as government can provide or search for other water resources (20 %). Agreed because they have got access to surface water or other water resources (20 %). Not response (1 %)
Water Resources Alternative for the Ground Water Usage Restriction for Industries	From the respondents that agree with the restriction of the groundwater usage for industries, 25 % of them agree if only the government facilitated the other water resources from the Water Supply Enterprises (WSE), another 25 % choose the alternative water resources from the Reuse/Recycle Water, and the other 37.5 % (most of the industries) not giving any alternative water resources answers if the restriction regulation has established.
Licenses and Capacity	Another information about the Industrial Water Resources Data is the licence of the water resources usage and its capacity. Having license (94.1 %), not answer (5.9 %) and no license (0 %). Out of that survey, 94,1 % of the respondents stated that they have the licenses, 52.9 %; the rest of them stated that the allowed capacity of the water resources usage has fulfilled their water demand. The others (35.5 %) did not answer, and (11.8 %) stated that the allowed capacity isn't fulfil the water demand.
Water Resources Quality and the Minimum Requirements for Production Process.	64.7 % of respondents stated that the quality of their water resources (surface and groundwater) do not fulfil the requirement quality as the process water, while the other 35.3 % stated that the quality of their water resources have fulfil the requirement for the production process water.
Water Tariff	Minimum tariff for the Surface Water Resources is 2,100,000 IDR/month, and 6,500,000 IDR/month for maximum. While the minimum tariff for the Ground Water Resources is 800,000 IDR/month, and 37,000,000 IDR/month for maximum.
Wastewater Discharge Volume	The minimum flow rates that can be generated by the industrial respondent is 10.000m^3/month, while maximum flow rates generated by those industries is 160.000m^3/month. <10.000m^3/month (0 %). 10,000 - <20,000 m^3/month (41.2 %) 20,000 - <30,000m^3/month (29.4 %).
Knowledge about the 'water recycle' term	94.1 % know the term of 'water recycling', while the 5.9 % did not answer the question.
Recycle Water Implementation in Industry	64.7 % of respondents stated that they have implemented the reuse/recycling water or rain water harvesting, while another 29.4 % stated that they had not implemented the Recycle water principal yet, and the other 5.9 % did not answer the question.
The motivation of the Industry to implemented the water reuse/recycling	- Economic factor - Water scarcity
Proposed Policy	- Improving the surface water quality (41.2 %) - Socialization of the Water Recycling Program (35.3 %) - Upgrade the water supply pipeline network (23.5 %)

Source: Data Questioner under SWMP, 2007

Basically there are some regulations which endorse to be implemented this water recycle program Regulation like Governor of West Java' Decree No 39 of 2000 about Standard for Raw Water, Governor of West Java' Decree No 9/1999 about Wastewater Standard for Industry Activities and Local Law about License for Wastewater Discharge are some of them. Those regulations state clearly that industry must obey and meet the required standards from both physical and biological aspects, but there are many obstacles that can be barriers for applying this program, namely (i) image of industry that water reuse and recycling is an "expensive effort" (ii) lack or insufficient disincentive and incentive mechanism, (iii) lack of national law to regulate incentive-mechanism, (iv) Insufficient law enforcement, (v) lack of support of management of industry, (vi) insufficient public awareness, (vii) less willingness to obey this proposed program from industry side because they have to spend some of their budget.

Here is a list of possible solutions and barriers of promotion of water recycling which were raised from industries in Bandung Water Recycle Meeting done in January 2007 under the SWMP research,.

Table 7. Proposed Solutions to Strengthen Water Recycle Program

Solutions	Stakeholders in charge of implementation
Support of management is one of the most important thing	Industry
It needs a recycling team to deliver or promote this program	Government
Incentive-Disincentive Mechanism	Government
It requires big invest to construct integrated industrial waste water plant	Government
Modifying of process production to decrease leakage of water in industrial process	Industry
Implement this program gradually	Industry and Government
Speed up the development of water infrastructure	Government
It is suggested to use biological treatment (technical solutions)	Industry
Develop public awareness on environment	Government and Community
Environmental credit/loan with low interest rate	Government

Source: Water Recycle Meeting under SWMP, 2007

5. Conclusion

High dependency of industrial sector on groundwater supply is one of the constraints of groundwater management in Bandung. The high dependency is closely linked with lack of infrastructure which is able to be provided by WSE. Currently, capacity of WSE for supplying clean water to industrial sector only reaches about 3.5 million m^3 in the year 2003. Calculation of actual volume of water supply of WSE compared to the requirement volume of industry sector concludes that water reaches less than 1 % of total industry requirement. The fact shows that almost all or most requirement of water of industrial sector is supposed to be fulfilled by groundwater supply. Another factor that influences scarcity of groundwater that should be addressed is decrease of groundwater recharge area. Groundwater recharge can interpreted as an additional process of groundwater from external area to saturated water column artificially. Generally, groundwater recharge can come from rainfall, river, and human treatment by such as recharge wells.

Besides that, the main issue of managing groundwater in the Bandung Basin is not just the problem of groundwater itself, but also involves complex problems concerning water scarcity in general, particularly in terms of industrial use. Land-use changes have negatively affected water resources, and the fact that there is no waterworks infrastructure for industry has made using groundwater the only option for carrying out industrial activities. Looking at groundwater control mechanisms in the Bandung Basin, licensing is still considered the main tool for controlling groundwater abstraction. But licensing does not work properly when there is only a minimum of awareness among stakeholders about the importance of groundwater conservation, combined with weak law enforcement and monitoring. This is shown by the fact that many unregistered deep wells have been found in the basin.

Water recycling is promising option to reduce the dependency on groundwater by the industrial sector. However, there is no incentive mechanism to promote water recycling, such as tax compensation to industry that promote water recycling effort, and therefore many industries are not interested in water saving efforts, which makes it extremely difficult to control groundwater extraction in Bandung Basin. Water Supply Enterprise inability to supply raw water and to extend its coverage area is also becoming a trigger to accelerate groundwater problems. Covering percentage by Water Supply Enterprise is approximately 37.75% (50 % for Bandung City, 23 % for Bandung Regency, 7 % for Sumedang Regency and 20 % for Cimahi City). The raw water for Water Enterprise mostly comes from surface water with biggest service to domestic use. Industry still depends on groundwater, and since the management is performed by the industry themselves, groundwater control becomes difficult.

The future challenge about groundwater management is adjusting the water provision mechanism that applies for the time being. The tax based on calculation of water value provision is divided in three components. The mechanism has been seen to give cheaper prices than price of water which is supplied by WSE. From calculation simulation with costliest component, the price which must be paid by using water provision value mechanism is much cheaper than tariff released by WSE. To 1-500m^3 relate to this mechanism will reside in price 1,038 IDR/m^3, to 500-1,500 is 1668 IDR/m^3, to 1,500 to 3,000 will reside in at spanning 2,298 IDR/m^3 and to 3,000 to 5,000 m^3 will be imposed around 3,138 IDR/m^3.whilst tariff of WSE is 1,750 to 9,600 IDR/m^3 for the usage of the industrial sector.

From the perspective of groundwater usage and management, it is urgent that a review of the situation be conducted for maintaining or recovering groundwater in Metropolitan Bandung. Efforts of maximizing surface water use and proposed water recycle program need supporting. There are 6 categories of measures that have to be developed, namely:

i. Institutional Measures: maximization of roles of related existing institutions through effective coordination with each other. Besides, establishment or development of a specific institution that handles the needs of water for industry in Metropolitan Bandung is necessary. The other important thing to conduct this program is composing a national strategy for water reuse and recycling as guidance for local or provincial level in term implementing it.

ii. Legal Aspect Measures: From the policy aspect, issuance of Law Number 22/1999 and the Revision Number 32/2004 on Local Government (Decentralization) has an implication to groundwater management. The law has given the authority for groundwater management to local government from the Directorate of Geology and Environmental in the centralized period. The decentralization could be another trigger in poor management of groundwater which is considered as a trans-boundary natural resource. Besides, it is necessary to amend groundwater regulations, particularly on how to enter critical points such as critical areas agreed on, or groundwater tax calculation of both technical and economical measures into the substance of that regulation. To promote voluntary commitment of industry for reuse and recycle program, groundwater and surface water shall be integrated and incentive and disincentive mechanism shall be incorporated into official regulations. Consistency in applying the existing or rearranging policy which will be issued such as giving penalty and license withdrawal to industries that exceed groundwater abstraction limits and applying Pollution Prevention and Polluter Pay Principle properly as agreed strategy in water resources development plan.

iii. Economic Measures: There are several recommended policies which were proposed in the stakeholders meeting conducted under the SWMP research. Such recommended policy includes establishment of incentive and disincentive mechanisms for use of groundwater, like reducing interest bank for constructing waste water treatment and water recycling facilities, and increasing groundwater charge or tax for industry use to the price higher than the water charge of WSE. In addition, if there are no incentive mechanisms in place such as tax compensation for industries that conduct water recycling, not many in industry are interested in water-conservation efforts, making it extremely difficult to control groundwater extraction in the basin.

iv. Technical Measures: In perspective of groundwater utilization and management, a review needs to be done with the aim of maintaining and recovering groundwater level and thus the carrying capacity of aquifers can be sustained. A policy alternative that needs to be conducted is to alter the water source from groundwater to surface water, particularly for industrial use. Another alternative is to relocate industrial cluster to other areas being designed as industrial estate, although relocation of industry to another location where surface water is abundant will also require development of new infrastructure. This option has a significant weakness in feasibility because of high investment, political and social cost that the national and provincial government has to bear. Introduction of appropriate and available technology for recycling is another alternative that can be implemented by industry in order to fulfil its water demand. Support of management in industry and consistency from government in the implementation is a key to achieve success of water recycling program.

v. Informative Measures: Through public awareness and education, like water saving awareness, the related stakeholders at each level should promote how to save water and disseminate both groundwater and surface water problem.

vi. Supporting Measures: Several recommendations were also proposed to cope with groundwater problems. The recommendations include establishment of groundwater proper monitoring system dealing with quantity and quality, land acquisition for conservation area in term of enhancing recharging aquifer both naturally and artificially, and trans-boundary integrated planning.

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CHAPTER 3-3

Water Resources Management in Ho Chi Minh City

1. Background to the Study Area

Ho Chi Minh City (hereafter HCMC) is located in the south of Vietnam, and is the biggest city in Vietnam. It is located from 10 10’ - 10 38’ North and 106° 2’-106° 54’ East. HCMC is 1,730 km from Hanoi and is at the crossroads of international maritime routes. The city center is 50 km from the East Sea in a straight line. It is a transport hub of the southern region and has the largest port system and airport in Vietnam. HCMC covers 0.6% of the total area of the whole country and has 6.6% of the total population. The city’s official population has increased from 3 million people in 1975 to 6.24 million people in the middle of 2005. However, the real population is supposed to be significantly higher than this because there are many unregistered people in HCMC. The real population could be around 7.5 million. The city natural land area is 2,095 km^2 with a present average population density of 2,687 persons/km^2. A map of the core area of HCMC is shown in figure 1.

Figure 1. Map of HCMC

There are about 30,000 factories in the industrial sector of HCMC, including many large enterprises, high-technology, electronic, processing, light industries, construction, building materials and agro-products. Currently, the city has 15 industrial parks (IP) and export-processing zones (EPZ). There are 171 medium and large scale markets, tens of supermarket chains, dozens of luxury shopping malls and many modern fashion or beauty centers. Over 50 banks with hundreds of branches and about 20 insurance companies are situated inside the city. In 2005, the city's Gross Domestic Product (GDP) was estimated at 11.6 billion USD, or about 1,850 USD/capita, (up 12.2% on 2004) and accounting for 20% GDP of the country. The city's Industrial Product Value was 5.6 billion USD, equivalent to 30% of the whole nation. Export - Import Turnover through HCMC ports took 29 billion USD, or 40% of the national total. Ho Chi Minh City has also contributed about 30% to the national budget's revenue annually.

2. State of Water Resources

At present, four water resources are used for water supply in HCMC. They are (a) Dong Nai River, (b) Sai Gon River (c) groundwater and (d) rain water. The current and projected total daily water use demand for domestic and industrial activities in HCMC were 1.75 million m^3 in 2005 and 3.6 million m^3 in 2020, respectively (Nga, 2006). The key water users in HCMC are residents, industries and services. Water resources used for agriculture in HCMC are (i) raw water taken from the irrigation canals network of Sai Gon and Dong Nai Rivers and (ii) storm water in the rainy season. Ground water has not been used for agriculture in HCMC because of (i) availability of fresh raw water of the irrigation canals located in the west and southeast of HCMC and (ii) unsuitability of groundwater quality for irrigation, such as high iron content and low pH.

The Saigon Water Supply Company (SAWACO) is responsible for exploitation, purification and distribution of water in HCMC. The capacity of piped water in 2006 under SAWACO's management was 1,236,000 m^3/day, which included 1,150,000 m^3/day produced by three surface water treatment plants taking raw water from Sai Gon and Dong Nai Rivers and 86,000 m^3/day produced from groundwater treatment plants.

2.1 Sai Gon and Dong Nai River

The total volume of water for domestic and industrial uses in HCMC was about 1,890,000 m^3/day in 2006, which included 1,270,000 m^3/day taken from Sai Gon and Dong Nai Rivers. Nga (2006) reported the maximum exploitation rates of freshwater from Sai Gon and Dong Nai River basins could obtain 7,500,000 m^3/day, which included:

- 940,000 m^3/day from Sai Gon River and up to 1,360,000 m^3/day when Phuoc Hoa reservoir is built,
- 200,000 m^3/day from Dau Tieng reservoir and Dong Canals,
- 6,000,000 m^3/day from Dong Nai River.

(1) Dong Nai River

Dong Nai River originates from Di Linh highland in Lam Dong province and connects to the East Sea through Soai Rap estuary. The total length of the river is 628 km. The total river basin area is 38,610 km^2. Other downstream sections of the river have an average slope of 0.22‰. The middle and upstream sections of the river have an average slope of 0.94‰ and 4.34‰ respectively.

The section of Dong Nai River in HCMC spreads from District 9 to intersection point with Nha Be River. Total length of this section is 40 km and average width is 200-300 m. The flowrate of Dong Nai River was from 100 m^3/s (maximum) to 32 m^3/s (minimum). However, when flow from Tri An reservoir was added, the flow rate increased to 2,110 m^3/s maximum flow and 600 m^3/s minimum flow. Due to the discharge rate of Tri An reservoir and Dau Tieng reservoir, a salinity limit of 4‰ is pushed back to Cat Lai, 10 km long from its first present point (Hiep Binh crossroad). When an additional flowrate of 20 m^3/s from Thac Mo lake is discharged to the Dong Nai River, the salinity point is 4-5 km further than its previous position.

Figure 2. Sai Gon - Dong Nai River system
Source: Triet et al. (2001)

(2) Sai Gon River

A section of Sai Gon River in HCMC begins from Phu My commune to Thanh My Loi, District 2. Width of the river is 250-350 m. The river depth is 10-20 m. Maximum flowrate was 84 m^3/s in October, 1986 (recorded at T3 station, Binh Duong Province) and minimum flowrate was 22.5 m^3/s in August, 1986. Maximum and minimum water level were 1.18 m (10th October, 1990) and -0.34 m (20 October, 1990). Sai Gon River is affected by semi-diurnal tidal flow regime.

Dau Tieng reservoir affects a large area of Sai Gon River basin (2,700 km^2). Its volume is 105 million m^3. It supplies water for irrigation and a clean water supply in Tay Ninh province and HCMC. The irrigation canal system of Sai Gon River is also a significant freshwater recharge source for the groundwater aquifers in the canals basin, located in the west and southwest of HCMC. Moreover, the lake also contributes to pushing back the salinity point because it discharges water to the downstream of Sai Gon River at a rate of 20 m^3/s. In Sai Gon River, there is a salinity point of 4‰ at Thu Thiem.

Water from Hoa An water intake station on Dong Nai River is pumped to Thu Duc water treatment plant (WTP) with a capacity of 650,000 m^3/day. Binh An WTP, which takes raw water from Dong Nai River, has 95,000 m^3/day. These two WTPs supply clean water for the eastern part and center of HCMC.

The Sai Gon WTP with a design capacity of 300,000 m^3/day (at Ben Than-Cu chi District) started running at a capacity of 120,000 m^3/day in 2004 and will be run at the designed capacity in 2007. It takes raw water from Saigon River and supplies clean water to the western part of HCMC.

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 years 2004, 2010 and 2020, respectively. The master plan of water supply of HCMC shows that Dong Nai River will be the main water uptake source, at which 57.3% and 62.3% of total water demands of 2010 and 2020 would be taken up, respectively.

Besides HCMC, the provinces of Sai Gon and Dong Nai Rivers basin such as Dong Nai, Binh Duong, Ba Ria-Vung Tau, Tay Ninh and Long An provinces also use Dong Nai and Sai Gon Rivers. The intake rate of Sai Gon or Dong Nai River water of these provinces is listed in table 1.

Table 1. The Intake Rates from Sai Gon or Dong Nai River Water of the Provinces in the Basin

No.	City/Province	Water Intake Rate (m^3/day)	
		2005	2020
1	Dong Nai province	100,000	300,000
2	Binh Duong province	32,500	50,000
3	Binh Phuoc	3,700	-
4	Tay Ninh province	5,000	-
5	Ba Ria-Vung Tau province	20,000	130,000
6	Lam Dong province	42,000	-

Source: VIWASE, 2004

2.2 Groundwater

HCMC has the following five aquifers, namely, (i) Holocene, (ii) Pleistocene, (iii) Upper Pliocene, (iv) Lower Pliocene and (v) Mesozoic.

Holocene: This aquifer contains sediments from different sources (rivers, sea, swamps). Main soil composition is clay, silt, fine sand loam, and a mixture of fine sand with botanical humus.
Pleistocene: Soil composition is clay silt, silt, sandy silt, fine sand. Some areas are weathered to laterite.
Upper Pliocene aquifer: The main materials of this aquifer are fine sand, a mixture of powder sand with fine sand. These materials create a continuous aquifer in which water can pass through.
Lower Pliocene aquifer: This aquifer contains fine and coarse sand, fine gravel and pebbles.

Over 150,000 wells/boreholes were exploited in HCMC. Three of five aquifers play an important role in water supply for HCMC: Pleistocene aquifer (20–50 m), upper Pliocene aquifer (50–100 m) and lower Pliocene aquifer (100–140 m).

(1) Pleistocene Aquifer (Q_{I-III})

Pleistocene aquifer is placed widely under the whole area and is exposed in the city center and Tan Binh, 2, 12, Thu Duc, Hoc Mon, Cu Chi districts. The aquifer includes 2 layers: (a) the upper layer is a weak impermeable layer and (b) the lower layer containing water.

(2) The upper Pliocene Aquifer (N_2^b)

The upper Pliocene aquifer (N_2^b) is not exposed at the surface. It is placed also widely under the whole city. The depth to the aquifer is about 40–80 m. The upper Pliocene aquifer is directly covered by the Pleistocene aquifer and placed above the lower Pliocene aquifer. The upper Pliocene aquifer includes 2 layers: impermeable and aquifer.

(3) The lower Pliocene Aquifer (N_2^a)

The lower Pliocene aquifer (N_2^a) is not exposed at the surface. It is placed widely in the project area. The depth to the aquifer is 50–100m. The lower Pliocene aquifer is directly covered by the upper Pliocene aquifer. The lower Pliocene aquifer includes 2 layers: impermeable layer and aquifer.

(4) Potentiality of Groundwater Resources

The Department of Industry (2002) estimated that the water reserve potential of all aquifers in HCMC was about 2,500,000 m^3/day. The water reserve potential of the aquifer was estimated from flows of recharging sources. Table 2 presents flow of sources recharging into aquifers in HCMC.

Table 2. The Reserved Fresh Water Potential of Aquifers in HCMC

No	The flow component	Pleistocene aquifer(m^3/day)	Upper Pliocene aquifer (m^3/day)	Lower Pliocene aquifer (m^3/day)
1	Flow recharged from rainwater	309,530		
2	Flow recharged from Dong Canal	156,750		
3	Flow recharged from Sai Gon River	67,500		
4	Flows from northern and western boundaries of HCMC	22,540	181,170	94,030
5	Static gravity flow	233,480	715,320	630,420
6	Static elastic flow	6,000	55,770	28,550
	Total	**796,000**	**952,000**	**753,000**

Source: DI, 2002

According to the drinking water standards of Viet Nam, water can be used for drinking purpose when the total dissolved solids level of the water is less than 500 mg/l as NaCl. The areas having three exploitable aquifers are the northeast of HCMC (Cu Chi district, Hoc Mon District) and the inner city. The areas having one or two exploitable aquifers are the East (Thu Duc, 9th, 2nd District) and the southeast of HCMC (Nha Be District, the west of Hoc Mon District and the east of Binh Chanh District). Other areas have aquifers containing brackish water (TDS higher than 100 mg/l as NaCl) or aquifers with low water potential quantity.

2.3 Rain Water

The rainy season in HCMC is from May to November. Rainfall in the rainy season is approximately 80–85% of the annual rainfall. Heavy rains occur in June and September in the range of 250-330 mm/month. The maximum is up to 683mm. Rainfall intensity is quite high (0.8–1.5 mm/minute). Therefore, rainwater use can be one of the important alternative water sources for HCMC. However, rainwater harvesting, storage and treatment for a big city like HCMC requires large investment cost and area. This becomes a great difficulty for developing countries such as Viet Nam. Rainwater use can be the suitable option for areas lacking freshwater or rural areas such as Can Gio District and District 7 or newly designed towns in the city.

Can Gio district’s population was 70,000 people in 2005. Can Gio is a district remote from the center of HCMC and currently there is no piped water distribution network and also no freshwater ground water resources. Rain water is one of the main fresh water resources for domestic uses. Because the groundwater of aquifers in Can Gio district have high salinity, now all residents use rainwater in rainy season and store it in dry season. There is a rainwater collecting system in most households which includes an Arris-gutter installed at the end of inclined house roofs for water collection. Besides, use of rain water, Can Gio district is provided clean water transferred from the center of HCMC by vessels. Vessels transport 5,000 m^3 from Nha Be District to Can Gio monthly. Sai Gon Water Supply Company is planning to install a water network for this area through the route of Nha Be – Can Gio districts.

2.4 Wastewater Reuse

A potential alternative water resource which may replace existing water resources for non-potable use is renovated wastewater. Advanced treatment of treated wastewater will yield a better quality effluent which can be used as an alternative water resource and therefore reduces the demand on fresh water supplies. The daily volumes of domestic and industrial wastewater discharged to the canals in HCMC were 710,000 m^3 and 35,000 m^3, respectively in 2000. The daily projected volume of domestic wastewater will be 2,100,000 m^3 in 2020. However, currently, only a small amount of municipal wastewater is conventionally treated at Binh Hung Hoa central wastewater treatment plant with a capacity of 30,000 m^3/day.

In addition, only 40%, approximately 15,000 m^3/day, of industrial wastewater has been treated efficiently by the centralized wastewater treatment plants located inside the five industrial parks (including Tan Thuan, Linh Trung 1, Linh Trung 2, Tan Binh, Le Minh Xuan, and Tan Tao industrial parks). The other 10 industrial parks in the city are still in the progress of setting up the wastewater treatment plant. The reuse of advanced treated effluent can be a good option for industry. However, the investment and maintenance for advanced treatment and secondary distribution networks for non-drinking water require huge budgets. Besides, the reclaimed wastewater management should be strictly controlled to reduce risks to human health such as pathogen contamination in the cases of poor control of effluent quality. Therefore, wastewater reuse can only be a good option for long-term planning.

3. Issues and Discussion on Groundwater Management

3.1 Groundwater Use

Groundwater has been used in HCMC since 1920. Rapid increase of groundwater use started in 1990 when the economic policies of Viet Nam were opened. High industrialization and urbanization resulted in the quick increase of water demands. The expansion of surface water works in HCMC has not met this rapid increase. Besides, until now free of charge groundwater and uncontrolled exploitation has increasingly augmented the exploitation rate.

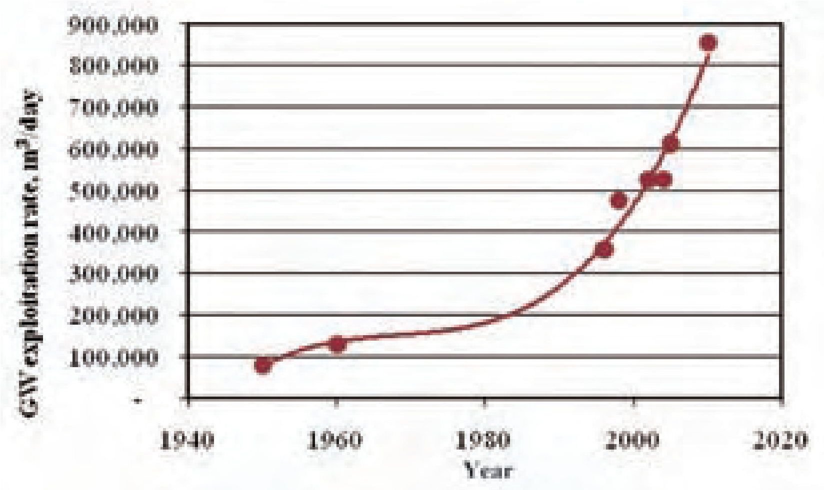

Figure 3. Variation of Groundwater Use versus Time in HCMC
Source: Nga, 2006

Nga (2006) reported that groundwater exploitation was estimated at about 611,000 m^3/day in 2005, of which 346,000 m^3/day and 265,000 m^3/day were used for domestic activities (residents, public works and services) and industry, respectively. The Union for Geology No. 8 (2001) assessed that the safe yield of all aquifers should be 500,000 m^3/day, whereas the DI (2002) and Nga report (2006) reported the safe yield could be up to 800,000 m^3/day. The safe yield is considered as the sum of dynamic potential and 30% of static potential of groundwater. The dynamic potential of groundwater is the difference between water volume in porous pores in rainy season and that in dry season. The static potential includes:

i. Static gravity potential is the amount of water contained in porous pores of aquifer. This potential depends on the depth of aquifer, exploitation time and aquifer area, etc.

ii. Static elastic potential is the amount of water released from the compressed aquifers as the water pressure of this aquifer decreases. Elastic static potential depends on water release coefficient and elastic volume coefficient.

The ratio of groundwater use was 34% of the total water demand of HCMC in 2005. The planning of groundwater use in HCMC (DI, 2002) reported that the projected groundwater use will be decreased by 21 % of the total water demand in year of 2010 and 15% in year of 2020.

At present, the groundwater use ratio of industry to piped water (water supply company) to individuals is 3:1:1. It should be changed to 2:2:0.5 in 2020. Thus, it is necessary to reduce groundwater use from industrial sector by encouraging wastewater reuse, water recycling, and applying different water tariffs of groundwater use for different sectors.

Groundwater still plays a non-replaceable role in water supply for HCMC at present, and will do so into the future. However, the groundwater is under threat due to salt water intrusion, water table descent and contamination of the shallow aquifer that have already been observed in some monitoring wells. Some daily papers reported that land subsidence had occurred at few areas with large exploitation capacity wells. Until now, no surveys on land subsidence have been done in HCMC.

3.2 Water Table Drawdown

Table 3 shows the annual water table drawdown at the areas with high well density.

Table 3. Water Table at Groundwater Monitoring Stations near the Areas with High Well Density

Aquifer	Year	Ground water table (m)				
		Binh Hung (Binh Chanh Dist.)	Tan Tao (Binh Tan Dist.)	Tan Son Nhat (Phu Nhuan Dist.)	Phu Tho (Dist.11)	Tan Chanh Hiep (Dist. 12)
Pleistocene	2000	-2.69	-2.61	6.76	-5.27	4.85
	2004	-5.6	-7.8	1.23	-7.96	3.8
	Total drawdown	*2.91*	*5.19*	*5.53*	*2.69*	*1.05*
	Annual drawdown	***0.73***	***1.3***	***1.38***	***0.67***	***0.26***
Upper Pliocene	2000	-8.18	-9.25	-11.58	-15.79	-7.71
	2004	-14.99	-18.57	-22.56	-23.67	-19.26
	Total drawdown	*6.81*	*9.32*	*10.98*	*7.88*	*11.55*
	Annual drawdown	***1.7***	***2.33***	***2.75***	***1.97***	***2.89***
Lower Pliocene	2000	-14.36	-8.94	-12.49	-15.85	-8.5
	2004	-29.75	-19.01	-23.12	-28.77	-19.9
	Total drawdown	*15.39*	*10.07*	*10.63*	*12.92*	*11.4*
	Annual drawdown	***3.85***	***2.52***	***2.66***	***3.23***	***2.85***

Source: DI, 2002

Figure 4 shows the water table drawdown cone may spread out larger and larger in the future years. The centers of the cone are the areas with high groundwater exploitation such as Hoc Mon water treatment plant, Go Vap District, Binh Tan and Binh Hung sub-districts (belonging to Binh Chanh district).

Figure 4. Water Table Drawdown of Upper Pliocene – 2010 in Comparison to 2001
Source: DI, 2002

(1) Pleistocene Aquifer
Along with northwest to southeast and from west to east, the water table was close to the ground level and tended to lower gradually. The biggest descent occurred at 05A (Phu Tho, District 11). In comparison to the water table in April 2001, the one in April 2003 was significantly lowered. The water table tended to lower gradually, 22 cm/year in 2002-2003.

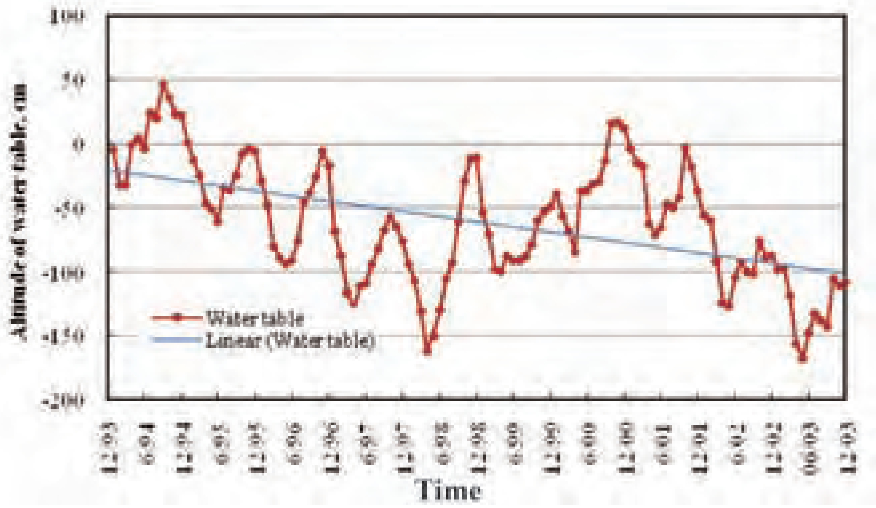

Figure 5. Change of Groundwater Table versus Time at Monitoring Station Q00202C (Cu Chi)
Source: Nga, 2006

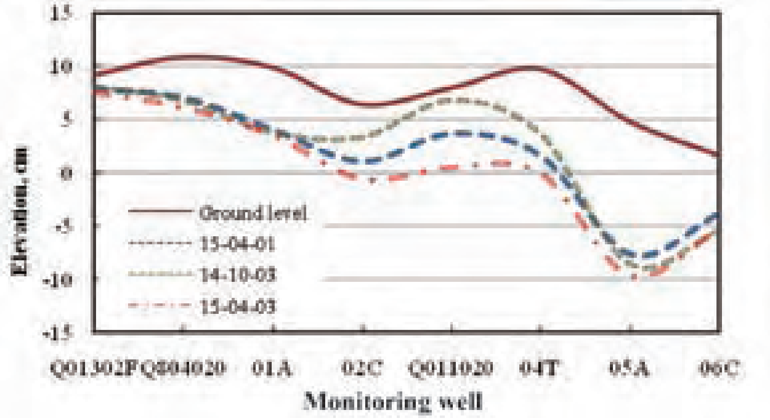

Figure 6. Water Table Profile of QI-III Aquifer along with Northeast – Southwest Line
Source: Nga, 2006

(2) The Upper Pliocene Aquifer (N2b)

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 station Q007, Q015030 (Binh Chanh); Q011340, Q017030, Q004 (Hoc Mon, district 12) the water table descended annually at an average of 0.11–1.95 m depth. 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 8).

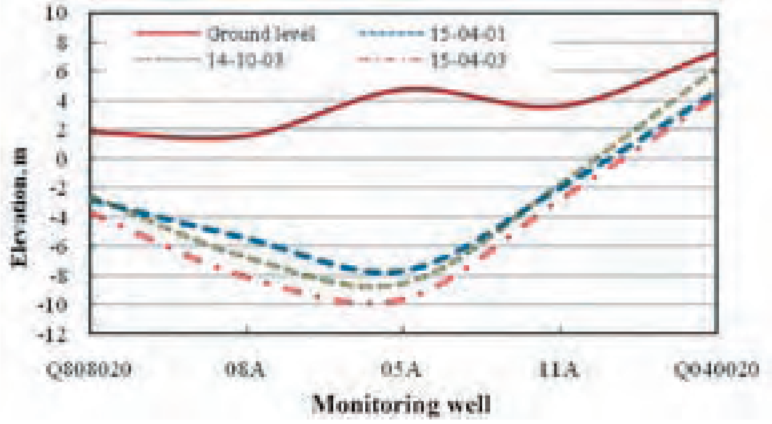

Figure 7. Water Table Profile of QI-III Aquifer along with West - East Line
Source: Nga, 2006

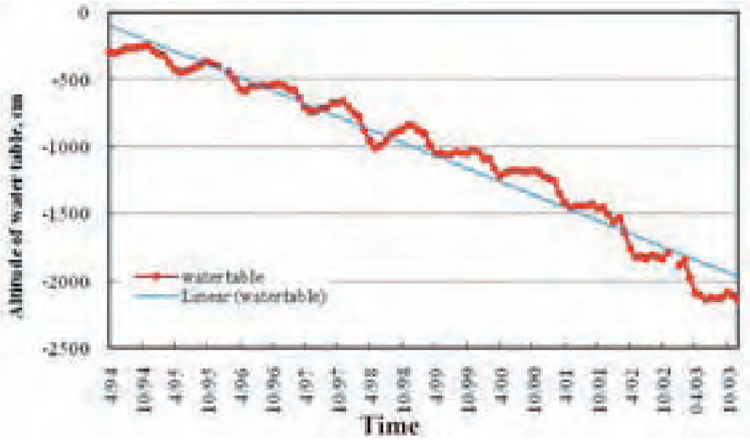

Figure 8. Change of the Groundwater Table versus Time at the Q015030 (Binh Chanh)
Source: Nga, 2006

Along the direction from northwest to southeast and from the west to the east, the water table changed slowly in Cu Chi, Hoc Mon and had tendency to descend in the city center.

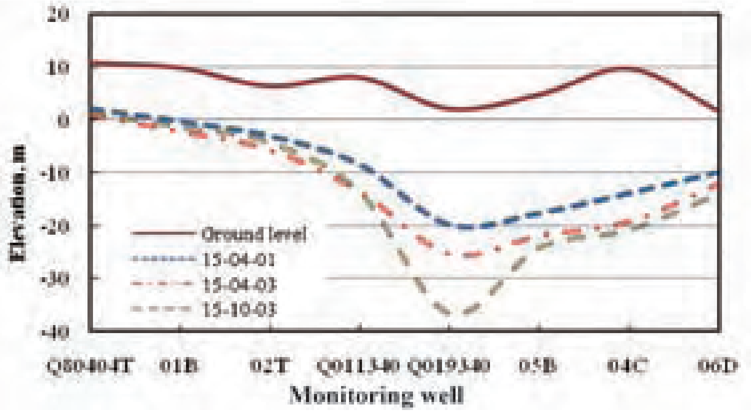

Figure 9. Graph of Water Table with NW – SE – Layer N2b
Source: Nga, 2006

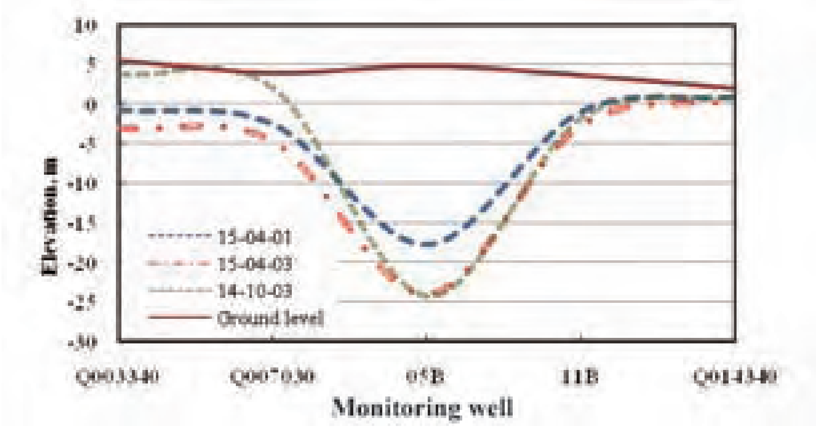

Figure 10. Graph of Water Table with W – E – Layer N2b
Source: Nga, 2006

The lower Pliocene aquifer (N2a): In general, the static water table of this aquifer is similar to that of the upper Pliocene (N2b). 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. This may be due to excess groundwater exploitation.

3.3 Groundwater Quality

The Union for Geology No. 8 reported that the number of damaged wells which could not be used due to salt intrusion was 2,359: equivalent to 2.48 % of all surveyed wells. Among the 11 monitoring wells, which were set-up under the DOSTE/UNDP project – VIE 96/023 during the first half of 2001, six of them have recorded nitrogen and pathogen-related contamination (nitrate, ammonium and coliform). In comparison to standards in TCVN 5944 – 1995 (Groundwater quality standard), the number of wells which exceeded standards for chlorine and pathogenic pollutants was 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 level of most 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) are not detected in all aquifers. Although Phenol and Cyanogen concentration still meet groundwater quality standards, they tends to increase with time and should be continuously monitored (Nga ,2006). The coliform contamination happened at some monitoring wells in the Pleistocene aquifer in 2002.

In 2003, among ten samples, coliform level of three samples exceeded the limited value of TCVN 5944-1995. In 2004, among ten samples, the coliform number of six samples was above the limited value. DONRE (2005) reported that Pleistocene and upper Pliocene aquifers were contaminated by coliform due to infiltration of domestic wastewater through wells with poor construction and maintenance.

TOC level of monitoring well ranges from 2.8 mg/l to 81 mg/l in 2004. In general, the average TOC concentration of GW is less than 2 mg/l under an uncontaminated environment (Deborah Chapman, 1995). Therefore, the groundwater in HCMC could be contaminated by organic compounds. The high TOC concentration is found in the following areas (i) Dong Thanh landfill (80.9 mg/l), (ii) Dong Hung Thuan-District 12 (18.1 mg/l), (iii) Bau Cat-Tan Binh (16.7 mg/l), Tan Tao-Binh Tan (13 mg/l) and (iv) Binh Hung-Binh Chanh (12.5 mg/l). TOC values at these locations in 2004 were higher than that of the previous years, while TOC at the other locations were stable.

Figures 11 and 12 show significant changes of isoline of 1,000 mg/l and 2,000 mg/l as chloride in 2000 and 2004, indicating serious salinity intrusion into groundwater sources (Nga, 2006). The isoline is a continuous one joining all points of identical concentration value.

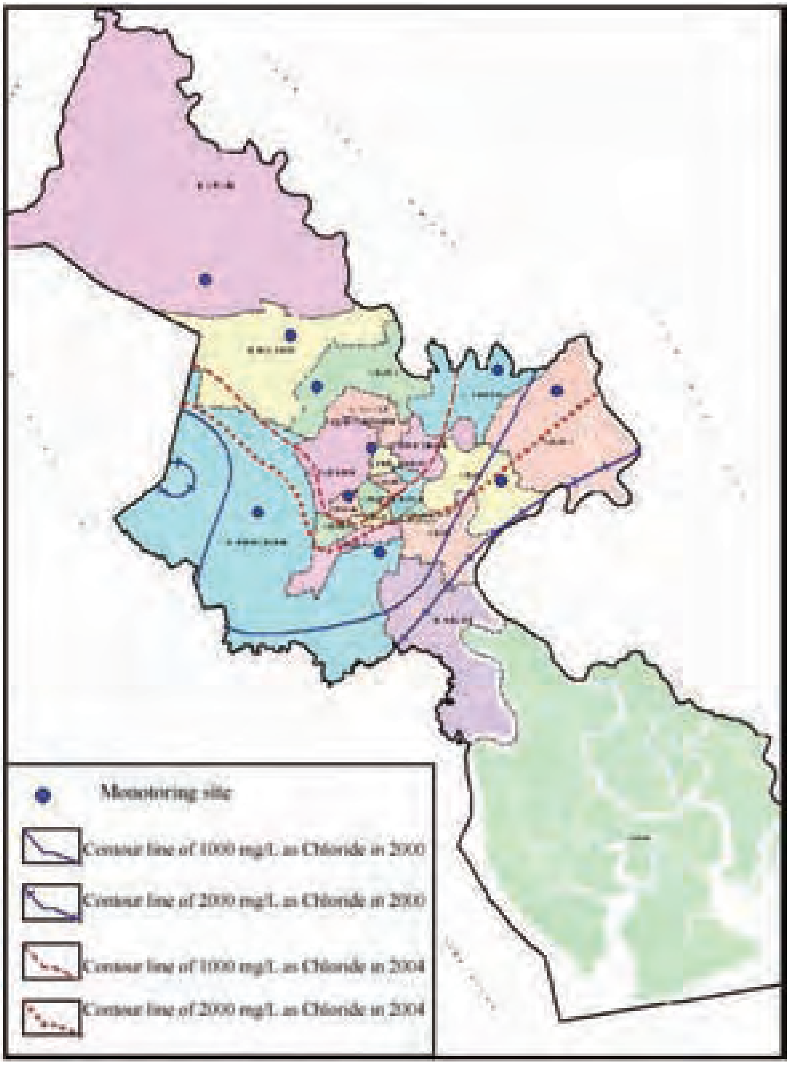

Figure 11. Map of Chloride Isolines of the Lower Pliocene Aquifer in 2000 and 2004
Source: Nga, 2006

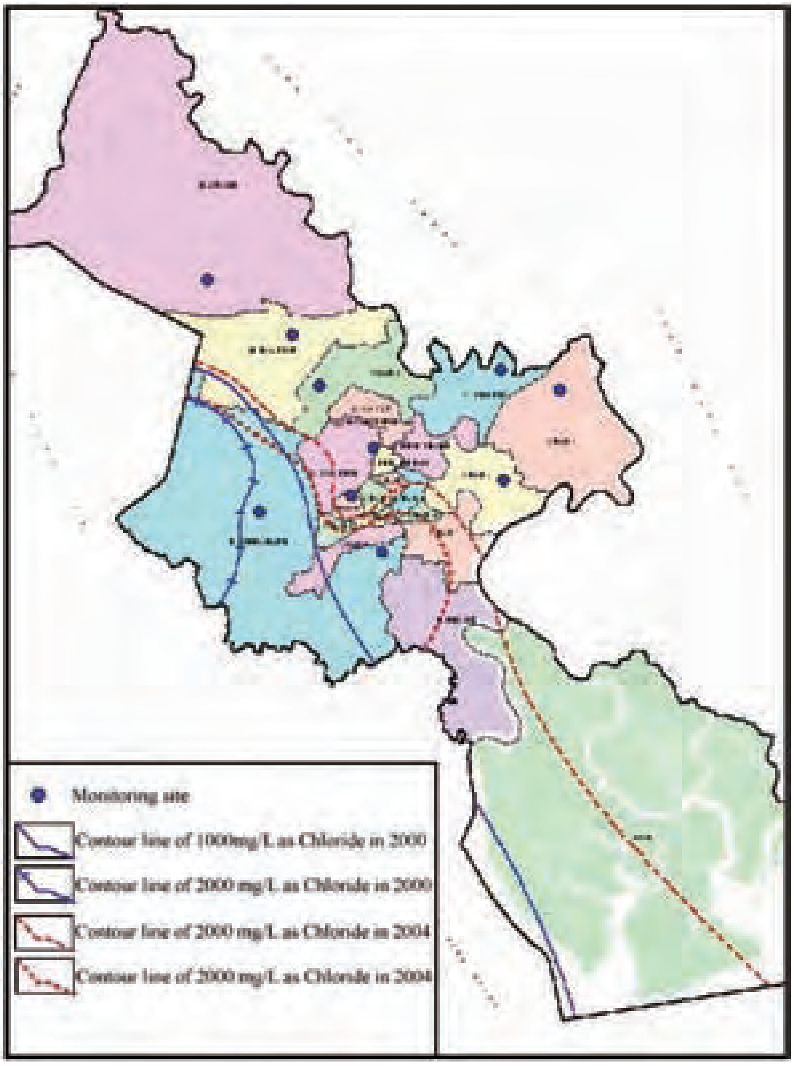

Figure 12. Map of Chloride Isolines of the Pleistocene Aquifer in 2000 and 2004
Source: Nga, 2006

3.4 Policy Measures and their Effectiveness

Groundwater management in HCMC has still been weak due to the following reasons (Nga ,2006): (i) lack of human and financial resources for control and management of ground water exploitation; (ii) weak coordination between relative departments such as DONRE, DI, DARD and DTPW; and (iii) lack of economic instruments for controlled groundwater exploitation (e.g. groundwater exploitation fee, regulations on limitation/prohibition of groundwater exploitation).

To control and protect water resources in terms of both quantity and quality, the Vietnamese Government has issued and implemented several regulations. Protection of quality of groundwater has been mentioned in the Articles 65, 74 and 75 of the *Environmental Protection Law, the Decrees* (e.g. Decree No.149/2004/NĐ-CP issued on exploring, exploiting and utilizing water resources and disposing wastewater to water sources; and Decree No. 34/2005/NĐ – CP about punishments for administrative violation in water resources) *and the implementation guideline documents* (e.g. Decision No. 17/2006/QĐ-UBND dated on 09/02/2006 on promulgating the regulation of water resource management in HCMC). These Articles issue the regulations of groundwater quality control for waste discharging sources and hazardous waste landfills. In addition, groundwater quality standards are given in the Vietnamese standard 5944:1995 issued by MONRE in 1995. A summary of the existing regulations on groundwater management is depicted in table 4.

Table 4. 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 as Decision No.17/2006
Regulations on limitation or prohibition of ground water exploitation in HCMC	Being compiled by DORNE
Draft guideline 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

Source: Dan, IGES, 2006

4. Analysis of Alternative Water Resources to Groundwater

As mentioned above, Ho Chi Minh City is now faced with a shortage and depletion of groundwater and there are efforts to study the alternative water resources of the city.

4.1 Principles for Analysis of Alternative Water Resources

The selection of alternative water sources is based on the following criteria:

i. Water quantity, such as reserve capacity, exploitation rate, ability of water intake and stability of quantity.
ii. Water quality, i.e. stability of raw water quality and principal key parameters of water quality.
iii. Water engineering, including water treatment technologies and clean water distribution engineering.
iv. Water economics, i.e. water exploitation charge, treatment/distribution costs, operation and management costs, and water tariffs.
v. Water management, compliance with master plans of water uses, management institution, available water sources laws/regulations, community acceptance, water intake ability.
vi. Risks: subjective and objective risks of projects relating to water sources, exploitation and water use.

Analysis of alternative water sources is shown in table 5. The analysis shows that surface water will be the prioritized alternative water source in comparison to the other water sources in terms of quantity, quality, technology, management, economics and risks. In addition, SWOP analysis for surface water sources is presented in table 6.

Table 5. Analysis of Alternative Water Sources in HCMC

Item	Surface water	Rain water	Brackish water	Reclaimed water
1. Quantity				
Maximum exploitation capacity	Abundant, about 7 million m^3/day, including 1.56 m^3/day from Saigon River and 6 million m^3/day from Dong Nai River.	Abundant, about 4.7 million m^3. Rainfall ranges from 1,800 to 2,000 mm/year, 80 –85% from June-August.	Abundant, especially in the coastal zone (District 7 and Can Gio).	The current wastewater quantity: • Domestic WW: 1,100,000 m^3/day of which 30,000 m^3/day is treated. • Industrial WW: 32.600 m^3/day of which 15,100 m^3/day is treated Above 2 million m^3/day in 2020.
Current water exploitation capacity	In 2004, SG River: 300,000 m^3/day DN River: 850,000 m^3/ day	Applied in the rainy season in some areas, not yet applied in large scale areas.	Currently, the brackish water is only used for aquaculture (shrimp and fish farms)	Unavailable
Ability of water uptake	Easy except duration of salt intrusion (few days in the dry season at Sai Gon River)	Easy (but only in 6 months of rainy season per year)	Easy (full year in coastal zone such as District 7 and Can Gio)	Easy to collect the effluent from the centralized wastewater treatment plants.
Stability	Good	Weak to medium depending on the rainfall	Good	Good
2. Quality				
Safety	Good for conventional treatment technology	Good for conventional treatment technology	Good for desalination technology.	Weak to medium, depending on operation and maintenance of the advanced wastewater treatment system, skill of operators, etc.
Stability	Medium, depending on seasons and pollutant sources	Good	Good	Weak to medium, depending on variation of raw wastewater.
Quality parameters to be treated	Sai Gon River: Low pH, high Mn, Fe, high SS, turbidity, pathogens, organic compounds.	pH, SS, pathogens	Pathogens, SS, high salinity	Non-biodegradable components, COD, trace organics, heavy metals, pathogens, color.
3. Engineering				
Exploitation engineering	Simple to medium depending on soil basement condition, water uptake capacity.	A rain harvesting and storage system requires high investment cost and large area	Simple to medium depending on soil basement condition, water uptake capacity.	Collection of effluents from the centralized wastewater treatment plants is simple.
Water treatment engineering	Conventional treatment: Coagulation-Flocculation-filtration and disinfection.	Conventional treatment: Coagulation-Flocculation-filtration and disinfection	Conventional treatment followed by desalination system.	Advanced treatment such as nutrient removal, SS removal, COD removal, adsorption, advanced oxidation, etc.
Distribution to users	The distribution network is available.	Use the available water distribution network.	Use the available water distribution network.	Separate water distribution networks for wastewater reuse. High investment cost and maintenance cost.
4. Management aspect				
Compliance with the water master plan	Intake capacity in 2010: + SG River: 750,000 m^3/day + DN River: 1,250 m^3/day Intake capacity in 2020: + SG River: 1,050,000 m^3/day + DN River: 2,250 m^3/day	The master plan for rainwater is not available yet.	A project on desalination system with capacity of 5,000 m^3/day prepared by a private company is under approval process.	Reclaimed water is not considered yet in the master plan of water supply in 2020 for aCM City.
Availability of Laws and Vietnamese Standards concerning water resources	The standards and laws are available and clear.	Unavailable for the standards and laws concerning use of rain water for water supply	Unavailable for the standards and laws concerning use of raw brackish water for water supply.	Unavailable for the standards and laws concerning wastewater reuse.
Suitability with the current management institution	Clear, managed by SAWACO, DONRE but weak organization for integrated river basin management.	Not available	Not available	Not available.

Table 5. (continued)

Community acceptance	High acceptance	High acceptance	Unknown	Difficult to be accepted due to water quality issue.
5. Risks				
Subjective risks	Water quality may degrade due to organic contaminants, pathogens, toxics by industrial and domestic sources.	Water quality may be effected by acid rains, excreta of animals living in the roof, fields, etc.	Water quality may degrade due to organics, pathogens, toxins by industrial and domestic sources.	Failure of operation and bad maintenance.
Objective risks	Salt intrusion	Lack of water quantity in the drought.		Unstable water quality due to variation of industrial & domestic wastewater.
6. Economic aspects				
Exploitation cost	Medium	High	High	Low
Operation and maintenance cost	Medium	Low	Very high	High to very high, depending on users.
Distribution cost	Medium	Medium	High	High
Water tariff	2,700VND/m^3	Unknown	Unknown	Unknown

Table 6. SWOP Analysis of the Surface Water Resources

Strength	**Opportunity**
- Quantity of surface water is abundant and stable. - Engineering of water uptake, treatment, distribution are stable and simple. - Surface water use is strongly acceptable by community. - Master plans and monitoring systems are available. - Management institutions are available and experienced.	- To decrease groundwater exploitation rate. - To increase use of surface water and piped water. - To upgrade the distribution networks and increase efficiency in water resource use.
Weak	**Potentials**
- It is easily contaminated by pollutant sources. - Water quality is unstable, extrused by salt. - Privation of water exploitation, production and distribution has not developed. - Upstream water quality monitoring system for whole basin is still weak. - Lack of upstream water protection programs. - Freshwater source is limited in the coastal areas such as Can Gio, Nha Be, District 7.	- To contribute to the sustainable development. - To increase the competition between users. - To enhance the capability and cooperation between river basin management unit, reservoir management unit, DONRE, DARD and DI. - To control water use demand through the policies and water tariff. - To increase the potential of building dam and reservoir.

In summary, the total potential of water exploitation per day for Ho Chi Minh city is about 13 million m^3 including 7 million m^3 from surface water, 4.7 million m^3 rain water and 1.3 million m^3 of groundwater. The existing exploited rate is 14.3% for surface water, i.e. 1 million m^3, and 46% for groundwater, while rain water has not yet been harvested. Therefore, it is noted that in addition to the fresh surface water source, harvested rainfall and brackish water are recommended.

4.2 Summary of Comments from Stakeholder Meeting on Alternative Water Sources

In order to provide a better understanding and to collect ideas from stakeholders on sustainable water resources management in HCMC, a stakeholder meeting on “Alternatives and Policies on Sustainable Water Resources Management” was organized on 26 January, 2007 in Ho Chi Minh City. The questionnaire was designed to collect the participants’ ideas on three main topics: (i) water resource alternatives, (ii) solutions to increase efficiency of surface water resource use; and (iii) measures to improve efficiency of groundwater use.

The results show that the predominant water alternative to groundwater was surface water (figure 13). Based on selection criteria and priority ranking, surface water is given first and second priority, followed by groundwater, rain water and then brackish and reclaimed water.

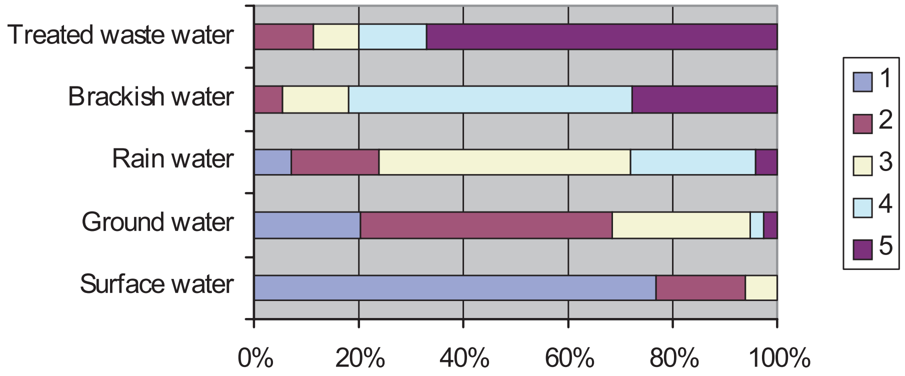

Figure 13. Ranking of Water Resource Alternatives based on Stakeholders' Comments
Note: 1: first priority; 2: second priority; 3: third priority; 4: fourth priority; 5: fifth priority

For both short term and long term developments, surface water is regarded as the first priority for water use (i.e. 100% of stakeholders agreed on this priority). Groundwater, in the short term (to year 2020), is regarded as second priority (92%) and third priority (8%), however, for long term planning to year 2030, groundwater was ranked less important compared with brackish water. It is ranked as second, third, fourth and fifth priority by 42%, 33%, 16.7% and 8.3%, respectively. Thus, in long term planning the function of groundwater could be decreased and, consequently, the groundwater demands will be reduced, considering the groundwater resources as the reserved water resources for water safety and emergency cases. Brackish water in the short term plan is regarded as the third (56%) and fourth selection (22%) but in the long term plan it becomes more important and will replace the deduction of groundwater and therefore it was ranked as second priority (33%). Rain water, in the short term, was ranked as third priority (50%) but later the significance of rain water decreased. Reclaimed water was less of a concern due to a lack of wastewater treatment systems and a lack of trust in the quality of treated water under current conditions.

During the meeting, the stakeholders proposed the following solutions for protection and improvement of surface water resources:

i. Treat pollutants from wastewater sources (33%),
ii. Control and prevent water pollution (33%),
iii. Protect water resources (25%),
iv. Water quality protection measurements (25%),
v. Develop integrated water river basin management (25%),
vi. Rationalize water resource uses (25%),
vii. Reasonably exploit surface water resources within their capacity (17%),
viii. Control the upstream water quality of Sai Gon - Dong Nai River basin,
ix. Inter-province and agency cooperation on reservoir management and water exploitation and regulation,
x. Reduce the water loss rate,
xi. Increase the awareness of water protection and water uses for local residents,
xii. Fine strictly the cases causing water pollution,
xiii. Apply economic tools such as water resources tax and increase water price.

According to stakeholders, the main groundwater consumers in terms of large water exploitation quantity in recent times have been industries, residents living in the areas without piped water supply or rural/suburban areas and poor people. 100% of stakeholders proposed that industries and the residential areas without piped water should pay a water fee of 4,000 and 2,000 VND/m^3, respectively, whereas, 65% of stakeholders suggested that the maximum water fee should be 2,700 VND/m^3 for rural people. In addition, 25% of them thought that they might stop using groundwater, while 33% of them thought that the poor people may stop using groundwater if the groundwater fee is applied. 42% of stakeholders suggested the water fee for poor people should be 500 VND/m^3 and 16% of them suggested that the maximum water fee for other users should be 3,000 VND/m^3.

5. Issues and discussion on the priority alternative source

5.1 Hydrology

Total area of canals and rivers is about 240 km^2, taking up 12% of the total area of HCMC. The total length of this canal system is 7,885 km. HCMC is at the convergence of Sai Gon and Dong Nai Rivers. Moreover, Vam Co Dong River, which belongs to the Mekong delta, also affects the hydraulic system of rivers and canals in the southwest of HCMC.

The canal and rivers system of HCMC is under the influence of a daily tide with high water level amplitude. HCMC is not significantly influenced by flood. The changes of water level in rivers have been unremarkable between 1960 and the present time. The Dong Nai River water level at Bien Hoa has changed only within 70 cm during the last 50 years. The variation of water level of Sai Gon River at Phu An is low (only 10 cm). When two big floods occurred in 1904 and 1952, the water level at Bien Hoa went up to 4.75 m and at Go Dau was higher than 1 m (up to 2.2 m). Two reservoirs in the upstream of Sai Gon and Dong Nai River are Dau Tieng and Tri An reservoirs, which were constructed for irrigation and hydropower in 1985 and 1989, respectively. These reservoirs help to control the water flow of Sai Gon and Dong Nai Rivers. In dry season, from February to April, Sai Gon and Dong Nai Rivers receive a flowrate of 20–22 m^3/s and 200 m^3/s for pushing salt intrusion, respectively.

As per the analysis of surface water availability and the water balance system of the Sai Gon - Dong Nai River basin mentioned above, the conflict of upstream water uptakes and downstream water quality and saline intrusion controls can only be solved when the releases from Tri An reservoir can be maintained at 300 m^3/s to downstream Dong Nai River, and the releases from Dau Tieng reservoir, with support from 50 m^3/s water transfer from Phuoc Hoa reservoir (which could be operational by 2010-2012), can be maintained at 40 m^3/s to downstream Sai Gon River.

5.2 Water Use

Water from Hoa An water intake station on Dong Nai River is piped to Thu Duc water treatment plant (WTP) with a capacity of 650,000 m^3/day. Binh An WTP, which takes raw water from Dong Nai River, has 95,000 m^3/day. These two WTPs supply clean water to the eastern and center parts of HCMC.

The Sai Gon WTP, with a capacity of 300,000 m^3/day, (at Ben Than Subdistrict) started at a capacity of 120,000 m^3/day in 2004 and will be run at the designed capacity from 2007. It takes raw water from Dong Canal of Saigon River and supplies clean water to the western part of HCMC.

The current total volume of raw water taken from both Sai Gon- Dong Nai Rivers is 1,150,000 m^3/day (including 3.5 m^3/s from Sai Gon Riverand 9.8 m^3/s from Dong Nai River). It will be 2,000,000 m^3/day (7.3 m^3/s from Sai Gon River, 14.5 m^3/s from Dong Nai River) in 2010 and 3,100,000 m^3/day (10.5 m^3/s from Sai Gon River, 23.7 m^3/s from Dong Nai River) in 2020. The intake rate from Dong Canal will be maintained at 3 m^3/s for the above future periods. The surface water exploitation capacity of 23.7 m^3/s for water supply on Dong Nai River in drought season does not cause any serious problem to the total flow rate of Dong Nai main river. It is not right to apply this idea to Sai Gon River because the exploitation rate 10.5 m^3/s is almost one-half of its total flow rate of 28.3 m^3/s in drought season.

5.3 Water Quality

Sai Gon - Dong Nai Rivers play important roles on economical and social development for 12 provinces, especially for the four key zones of economic development including Binh Duong, Dong Nai, Ba Ria Vung Tau and Ho Chi Minh City. Those zones include 54% of the industrial productivity and 60% of exporting value of the whole country. These zones have 47 existing industrial parks and 72 projected industrial zones in 2020, which may seriously threaten the water quality of Sai Gon - Dong Nai Rivers. Only 14 of 47 existing industrial parks have wastewater treatment systems.

Besides industrial parks, there are many tapioca and sugar processing industries with high organic pollutant loads which are located in the upstream basin of Sai Gon and Dong Nai Rivers. High pollution load from more than 57,000 small-scale industries in the basin is also discharged directly into the rivers.

Triet et al. (2005) reported that 44 industries of 47 existing industries discharge 111,065 m^3 of wastewater containing 15 tons TSS, 77 tons COD, 20 tons BOD_5, 1.6 tons nitrogen and 542 kg total phosphorus daily to Sai Gon - Dong Nai Rivers. Sai Gon River received 27% total volume of industrial wastewater and the maximum BOD_5 amount was 12.5 tons BOD/day (i.e. 63.8% total BOD emitted from industries). Dong Nai River received 35% total volume of industrial wastewater and the highest amount of TSS (6.9 tons), COD (33 tons) and total nitrogen (0.7 tons) per day which is 46%, 43% and 47% of total emission, respectively.

Besides industrial wastewater, domestic wastewater from urban and residential zones and runoffs from agricultural and landfill, animal farms have threatened the quality of surface water. There are about 116 residential areas in the Sai Gon - Dong Nai River basin belonging to four cities, 19 districts of Ho Chi Minh City and 85 towns with a total population of 8,399,338 in 2004, of which the population of HCMC was approximately 74%. Distribution of residential areas is not even among provinces; they are mostly located along Sai Gon River, with 27 residential areas and 5.75 million residents. There were about 1 million m^3 domestic wastewater containing 375 tons TSS, 244 tons BOD_5, 456 tons COD, 15 tons N-ammonia, 8 tons of total phosphorus, and 46 tons oil and grease, etc., discharged directly to rivers without treatment. Most residential areas, both new and old ones, do not have domestic waste water treatment, and therefore, it results in an increase of organic pollutants and more risks of water-borne diseases related to bacteria and viruses. Sai Gon River received 76.2% of the total volume of domestic wastewater and the highest BOD_5 amount of 243 tons BOD/day (i.e. 66% total BOD emitted from domestics) and 69% of total oil and grease. Downstream, Dong Nai River received 15% of the total volume of domestic waste water and about 18% of total pollutant loads. In addition, there have been pollutants contributed from (i) the 73 solid waste dumping sites without leachate collecting and treating systems, most of which are located near the canals or rivers; (ii) water runoffs from 1.8 million ha agricultural land carrying suspended solids, fertilizer and pesticide residues, acidity from acid sulphate soil into the rivers; (iii) wastes from animal farms and aquaculture farms; and (iv) wastes from accidents due to activities of navigation and ports (about 30 operating ports). Triet et al. (2003) estimated BOD_5 variation with distance from upstream to downstream and time in the figure 14 and BOD_5 in the upstream was less than 5 mg/l, whereas it increased to 10–15 mg/l in the downstream in 2001 in the figure 15.

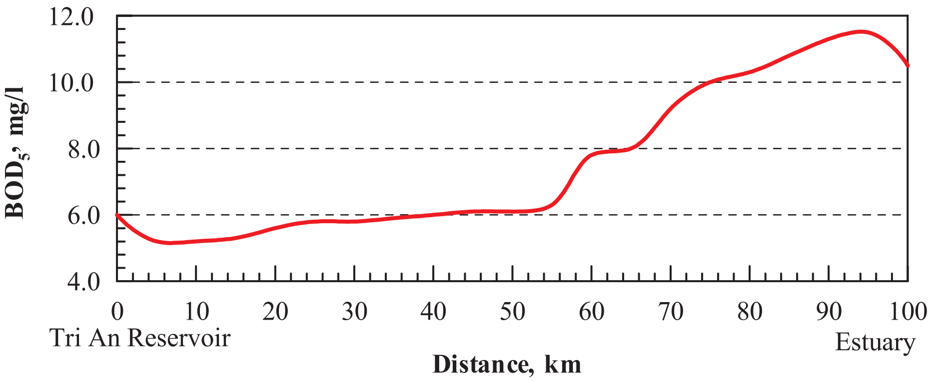

Figure 14. BOD_5 Variation along Dong Nai River
Source: Triet et al., 2003

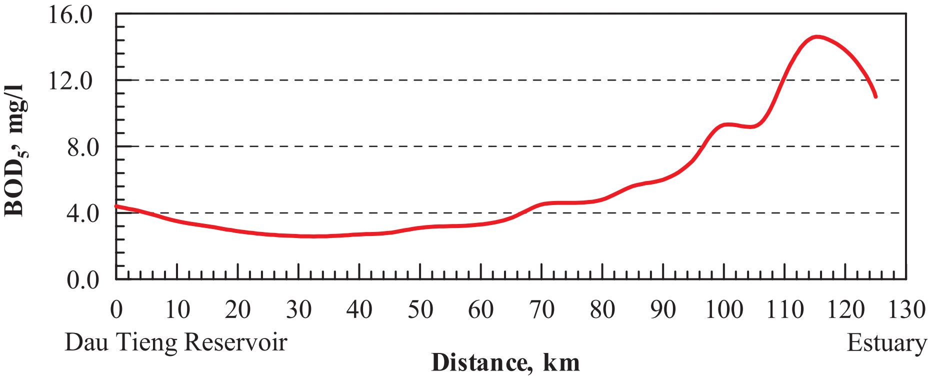

Figure 15. BOD$_5$ Variation along Saigon River
Source: Triet et al., 2003

Monitoring report of HEPA (2004) from eight surface water sampling stations show that Saigon River water is known to be affected by acidic soil, showing slightly acidic pH at Phu Cuong Station, near the water intake for municipal water supply. pH varies significantly and sometimes drops below 5. A sudden change of pH makes water treatment and land development difficult. The exposure of acid sulphate soil to water is suspected to further exacerbate the acidic water problem. Total coliform number increased after 2000, varied significantly in 2003 and remained at a higher level in 2004. The data on total also indicates contamination of Saigon River water due to human activities. Takizawa et al. (2004) showed that Saigon River is more contaminated than Dong Nai River because of human activities and lower flow rate. SS fluctuated between 1 mg/l and 9 mg/l in 2004. Another problem in the last few years was high turbidity in the dry season, which makes water treatment more difficult.

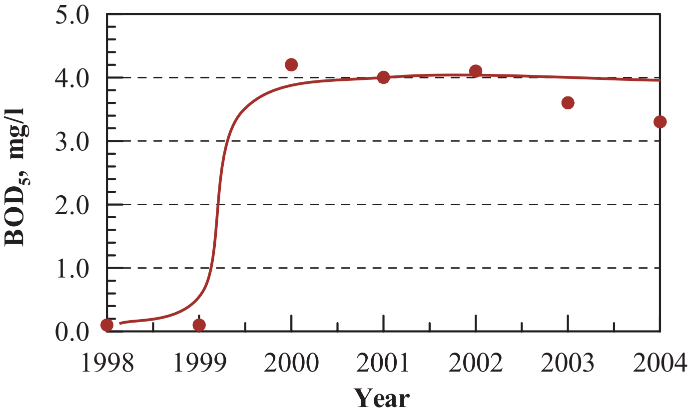

Figure 16. Variation of Average Annual BOD$_5$ versus Time at the Hoa An Water Monitoring Station (Dong Nai River)
Source: HEPA, 2006

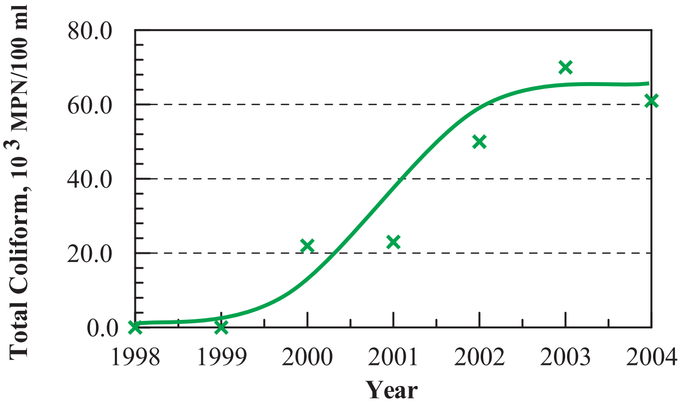

Figure 17. Variation of Average Annual Coliform with Time at the Hoa An Water Monitoring Station (Dong Nai River)
Source: EPA, 2006

Water quality of Dong Nai River at Hoa An (water supply intake) is also getting affected by discharges from the upstream basin. The water quality survey conducted during this study, of which locations are illustrated in figure 2, shows that BOD_5 varies between 5-9 mg/l. According to Vietnamese standard TCVN 5942-1995, BOD_5 of surface water for domestic water use should be less than 4 mg/1. The result of the monitoring program in 2004 showed that fecal coliforms also exceeded the limit in dry season, especially during low tide.

Table 7. Water Quality of Saigon-Nha Be River

Site	Direction	DO (mg/l)	pH (mg/l)	SS (mg/l)	COD (mg/l)	Total P (mg/l)	Total N (mg/l)	Oil and grease (mg/l)	Coliform (MPN/100ml)
Thu Dau Mot (Upstream)	Upstream	4.3 - 4.4	5.9	2 - 5	11	0.08	1.5 - 1.8	0.1 - 0.3	2.10^5 - 8.10^6
Binh Phuoc	↓	5.0 - 5.1	6.2 - 6.4	2 - 3	9 - 11	0.10	2.3 - 2.7	0 - 0.1	15.10^3 - 9.10^4
Nha Rong Harbor		4.2 - 4.6	6.8 - 7.0	4	8 - 9	0.10	2.4 - 3.2	0 - 0.2	1.10^4 - 5.10^4
Sai Gon River estuary		3.3 - 3.4	7.2 - 7.3	9 - 12	12 - 16	0.15	1.6 - 2.2	0.1 - 0.2	7.10^4 - 12.10^4
Binh Khanh ferry	Downstream	3.1 - 3.2	7.7	7 - 25	9 - 23	0.05	1.4 - 1.5	0.1 - 0.2	6.10^3 - 31.10^3
TCVN 5942-1995	Type A	> 6	6.0 - 8.5	20	10	Unavailable	(*)	Not detected	5,000
	Type B	> 2	5.5 - 9.0	80	35	Unavailable	(*)	0.3	10,000

Note: Type A – Water resource for domestic water supply purposes

Type B – Water resource for agriculture and navigation purposes

(*) no standard applied for total nitrogen concentration, however, for Ammonia: 0.05 mg/l for type A and 1.00 mg/l for type B; Nitrate: 10 mg/l for type A and 15 mg/l for type B; and Nitrite: 0.01 mg/l for type A and 0.05 mg/l for type B.

Source: CEFINEA, 2003

Average BOD_5 of Saigon River at Nha Rong was as high as 16 mg/1 in the year 1997 compared with 10 mg/1 in the year 1993. The water quality survey conducted during this study reveals that the level of pollution in the upstream reaches of Saigon is low, however it is quite high at Nha Rong after receiving wastewater from Tau Hu - Ben Nghe Canal and Doi - Te Canal. BOD_5 at Tan Thuan was found to vary from 30 to 75 mg/1. Fecal coliforms were also about 1.1 E+07 MPN/l00ml. Concentration of pollutants in Saigon River is higher than the allowable maximum limit for domestic use/other uses. Saigon River is an important source of aquatic products. If organic pollution is not controlled, DO in Saigon River will be depleted further, making it impossible for fish and other aquatic organisms to survive. The less tolerant migratory fish are unlikely to survive if DO is less than 4 mg/1. Water quality at Nha Be is improved compared with Saigon River. DO is increased to 7–7.8 mg/1. Nha Be is subjected to tidal influences and salinity intrusion and is not a suitable source for drinking water supply.

The dense rivers and canals system, which receives discharge in HCMC, involves five main canal systems. They are Tan Hoa - Lo Gom Canal, Tau Hu - Kenh Te-Ben Nghe Canal, Nhieu Loc - Thi Nghe Canal, Tham Luong - Ben Cat - Vam Thuat River and Xuan Truong - Suoi Cai Canal.

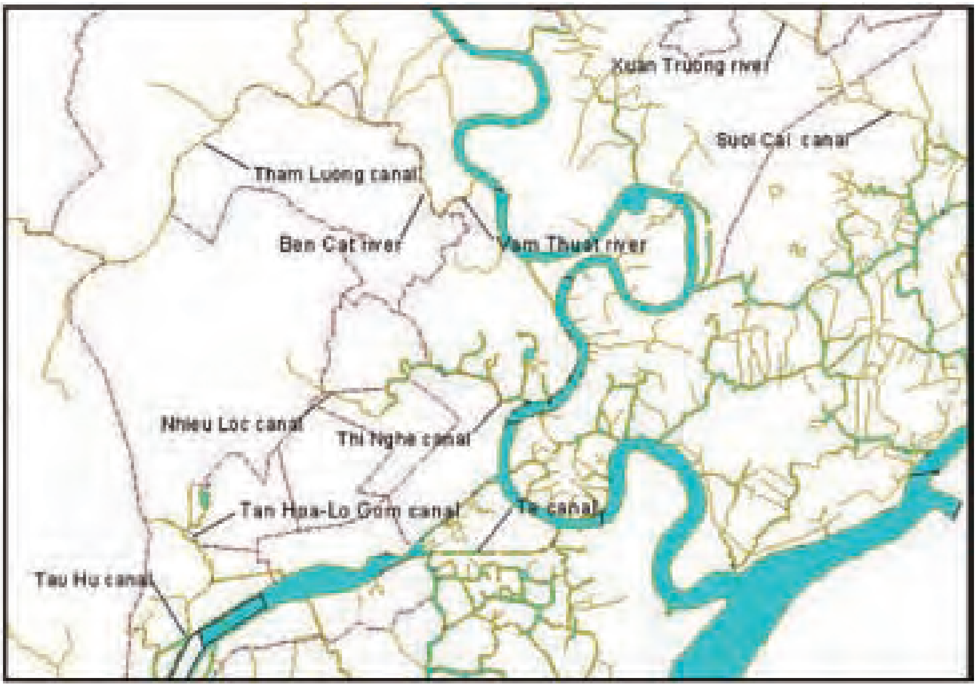

Figure 18. Main Canal Systems in the Inner City

It is perceptibly recognizable that all canals in HCMC have been heavily polluted. The bad smell is frequently emitted and is worse at low tides. The monitoring data shows most canals in the inner city are affected by tide. With semi diurnal tidal influence, the tide does not go fully down once it rises, so in the upper parts pollutants are received and accumulated and do not move away. The DO of these canals at the low tide is 0 mg/1 and BOD$_5$ ranged from 120 to 210 mg/1. Water quality is slightly improved at the points near Saigon River. The fecal coliform count of canals at low tide in dry season was 1.5×10^5 MPN/l00 ml. Domestic wastewater is the main source of pollution for Nhieu Loc Canal.

Ammonia-nitrogen concentration is high, ranging from 6 to 29.8 mg/l. Tham Luong – Vam Thuat, Xuan Truong-Suoi Cai and Tan Hoa-Lo Gom Canals have been severely polluted by industrial wastewater. These canals receive industrial effluents. DO is almost depleted in this canal. BOD$_5$ varies from 100 to 200 mg/1. Fecal coliforms vary between 1.5×10^4 -2.1×10^6 MPN/100 ml. High coloration of the canal water is due to direct discharge of effluents from textile and dyeing industries. BOD$_5$ ranges from 180 to 360 mg/l. The solids of the wastewater are settled down and accumulated in the canal beds. The canals are in an anaerobic phase and emanate a bad smell of CH_4 and H_2S during low tide.

The daily wastewater quantity discharged into the canals in HCMC was 710,000 m^3/day in 2000 and will be 2,100,000 m^3/day in 2020. The BOD$_5$ load was 170 tons/day in 2000 and projected load will be 380 tons/day in 2020. In addition, the domestic and industrial wastewater of 729,000 m^3 with a pollution load of more than 193,000 kg in terms of BOD$_5$ is discharged daily to rivers and canals in the Study Area without any treatment. At present, about 30,000 m^3/day of domestic wastewater and 15,000 m^3/day industrial wastewater from 5 of 15 industrial parks in HCMC are conventionally treated.

5.4 Piped Water

The existing water distribution network has a total length of 32.811 km. In 2001, 75% of the population in the urban area was supplied with clean water. The water consumption was between 50 and 100 liters/capita/day. In the suburbs, except for Cu Chi and Can Gio Districts, 21% of the population is supplied with water at a consumption of 20 to 40 liters/capita/day. The report of Master Plan of Water Supply System in HCMC (2005) showed that the percentages of piped water for domestic, industrial and commercial purposes are 71.5%, 22% and 6.5%, respectively. The average ratio of the population supplied clean water is 75%, and the water loss is now 35–37%. The forecasted ratio of piped water, water loss and water capita are shown in the Table 3.2. The target of Sai Gon Water Supply Company is to decrease water loss to 26% and increase 25–30% piped water in the next 10 years. This is one of the great challenges.

Table 8. The Forecasted Ratio of Piped Water Supply, Water Loss and Water Demand

Items	Year		
	2005	2010	2020
Domestic water demand (l/capita/day)	160-180	180-200	200-220
Ratio of piped water supply (%)	75	95	100
Water loss (%)	37	26	Unavailable

Source: VIWASE, 2004

6. Challenges and Recommendations to Water Resources Management

6.1 Main Challenges to HCMC Water Supply

Based on analysis of the state and the issues of water resources in HCMC, the study identified the seven main challenges for water resources management that are directly related to water supply for HCMC as follows:

i. Cooperation on water regulation of integrated rivers and reservoirs systems.
ii. Control industrial pollution.
iii. Control surface water quality.
iv. Limitation of groundwater use and rationalization of groundwater uses among sectors.
v. Control salinity intrusion of groundwater sources.
vi. Decrease rate of water loss, accompanied by development of water distribution system.
vii. Enhance awareness of water saving and conservation for public, communities and enterprises.

6.2 Policy Recommendation for Better Water Resources Management

Not only to overcome the seven challenges of HCMC water supply but also to achieve the sustainable water resources development, the study has proposed six recommendations (numbers 1 to 6) in short-term planning and two recommendations (numbers 7 and 8) for long-term planning. The recommendations were proposed based on the situation and future analysis taken into account of the existing Vietnamese water regulations and laws and the national development strategies. The main strategies and policies are used in follows:

- The national environmental protection strategies in the period 2001–2010.
- HCMC environmental management strategies to 2010.
- The plan of groundwater use in HCMC to 2010.
- The surface water protection strategies in HCMC to 2010.
- The master plan of water supply in HCMC to 2020.
- The master plan of drainage system in HCMC to 2020.

The main objectives of those strategies are to improve water resources management, including (i) to protect groundwater resources by reduction of the exploitation rate to a value of below 500,000 m^3/day by 2010 and (ii) to improve the quality of surface water of the Dong Nai & Sai Gon Rivers upstream. The water quality should be reached the National Standard TCVN 5942–1995–class A by the year 2015.

Implementation of Integrated Basin Water Resources Management: As mentioned above, the Sai Gon - Dong Nai River Basin Organization (RBO) was established in 2003 and has been operating for four years. However, it is likely that they only exist on paper and work inefficiently. On 31 May, 2005, the roundtable meeting among provinces and HCMC was organized and chaired by the Minister for Environment and Natural Resources and the Vice Chairman of Ho Chi Minh City People's Committee to propose the cooperation mechanisms on environmental protection in Sai Gon-

Dong Nai River basin. Therefore, it is necessary to:

i. Enact and push up activities of SG-DN RBO. Unanimously manage water resources and water regulations.
ii. Establish the cooperation mechanism and continue to organize the round-table meetings regularly to share information, responsibilities and rights of use and protect water resources in Sai Gon - Dong Nai River systems among the provincial stakeholders, experts, researchers and decision makers.
iii. Maintain and develop the information systems for SG-DN basins. The basin information system can consist of maps, charts, databases, electronic data, basin profiles relating to water resources and other economic and social activities affecting water exploitation and use in basin. That information could be used for setting up sustainable water resources management.

Control of pollution emission:

i. Relocate the polluting industries into industrial zones and limit the wet industries in Sai Don-Dong Nai basins.
ii. Set up and enforce the operation of centralized wastewater treatment plants in industrial zones.
iii. Encourage enterprises to apply cleaner production, save water and use reclaimed water.
iv. Develop the model of sustainable green city in Sai Don-Dong Nai basins.
v. Enhance the implementation of integrated pesticide management (IPM), integrated nutrient management (INM) for agriculture and breeding.

Limitation of groundwater use:

i. Apply the groundwater charge system for groundwater exploitation for different target groups. The industrial sectors will be applied at the highest rate of groundwater fee to encourage the enterprises saving water.
ii. Enforce the implementation of water regulations on zoning the risk, vulnerable or exploited areas of groundwater sources, for example, the Decree No. 149/2004-NĐCP, dated 27/07/2004, about regulations for issuing licenses for water resource exploitation and emission to water sources; the Decree No.34/2005-NĐCP about regulations of administrative penalty for contaminating water resources; the Decision No. 17/2006/QĐ-UBND dated 09/02/2006 about promulgating water resource management in HCMC.
iii. Set-up and implement the pilot programs of groundwater recharging with the preliminary treated run-offs.

Reduction of the water loss rate due to the improvement of water projects and services:

i. Prioritize and call for investments on water development projects (for example projects to improve the water loss rate and to extend water distribution system) as well as wastewater treatment and water supply projects.
ii. Re-organize the public water services, transfer the irrigation management to water use association.

Upgrade water tariff:

i. The current water tariff needs to be reviewed and upgraded. The existing water-production price contains the cost of property depreciation (65%), the electricity cost (10%), the labor cost (10%) and the operation and management cost (15%). Therefore, the government should stimulate and favor water development projects and, in consequence, the cost of property depreciation due to water production could be reduced, resulting in reduced water production prices.
ii. A special water price for poor people, i.e. people who use less than 2 m^3 water/capita/month, should be applied. (The World Bank's standard is 1.2 m^3/capita/month.)
iii. Set up and enforce economic tools for water management such as water resource tax, water use and conservation fee, groundwater fee.

Encouragement of water saving and reasonable water use:

i. Stimulate applying the cleaner production technology and recycling water in industries.
ii. Encourage using reclaimed water or recycling water for such services as hotels, office buildings and other entertainment facilities such as water parks, swimming pools, fishing clubs, etc.
iii. Enhance the awareness of water saving and environmental protection in the community.

Enforce to recycle water and use reclaimed water for industries and agricultural activities

Stimulate the use of harvested rain water for domestic purposes and reclaimed water for industries and agriculture and brackish water for aquaculture as the supplementary water resources

7. Conclusion

(1) Groundwater management strategy, a part of Ho Chi Minh City environmental management strategies up to the year 2010, approved by Ho Chi Minh City People's Committee, expresses the major subjects for water resource management in Ho Chi Minh City, including surface water and groundwater as well as other matters of urgency:

- Over exploitation of ground water which has limited reserve,
- The surface water source of Sai Gon and Dong Nai Rivers becoming gradually polluted,
- The close relationship between surface water and ground water in water exploitation and water recharging balance.

The main objective is ground water preservation by reasonable exploitation and the use of ground water, controlling the abstraction rate at less than 500,000 m^3/day and minimizing the adverse impacts on ground water such as ground water contamination, salt intrusion, drawdown of ground water level, and land subsidence.

(2) To achieve sustainable groundwater management, the alternative water sources should be focused on for future water use. Through SWOP analysis (analysis of strengths, weakness, opportunities and potentials), situation analysis and expertise analysis, water from Sai Gon and Dong Nai Rivers is the priority selective source. Although the SG-DN River basin has plentiful water, water quality has gradually declined due to conversion of land use, agricultural and industrial activities and rapid urbanization and especially poor management. This results in adverse effects on the fresh surface water used for water supply to HCMC. Strategies on protection of surface water resources, including water use and management of urban sewerage system of HCMC, were issued and step by step developed the implementation through the action plans. However, this implementation has faced some difficulties, such as the lack of financial sources, the weakness of capacity of integrated management, and the poor coordination between authorities of neighboring regions.

(3) The study has proposed eight main policy recommendations for Ho Chi Minh City to overcome the barriers and challenges of future water use and to achieve better water resources management. Many efforts need to be spent to implement those policies. The policies on the integrated basin water resources management and the pollution control are critical and urgent.

(4) Rain water or reclaimed water in suburban areas where the piped water or fresh water is not available may be the alternatives for domestic and industrial uses. Desalination of brackish water in Can Gio province's coastal zone will be one of the feasible alternatives.

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CHAPTER 3-4

Challenges and Prospects of Sustainable Water Management in Tianjin

Introduction

Tianjin, one of the biggest cities in the northern China, is badly short of water resources due to its natural geographic and climatic condition. In Tianjin, water availability per capita is 160 m^3, which is only 1/15 of the national average, and 1/60 of the world average. Due to its severe shortage and over-exploitation of groundwater, Tianjin is now facing many problems such as land subsidence and pollution of irrigation wastewater, which will restrict the sustainable development of the social economy. As a new, useful, potential and unconventional water resource, reclaimed water shall be broadly used to improve the unsatisfactory situation of water utilization in Tianjin.

In this paper, based on an analysis of the status quo of water resource use and water management policies in Tianjin, not only are the unreasonable groundwater exploitation and incomplete water management system discussed, but the authors also give a detailed analysis of water management policies in past years, and put forward relative suggestions and recommendations for the sustainable management of water in Tianjin. In the near term, speeding the pace of the popularization of reclaimed water and improving the efficiency of the scientific use of all water resources will be the most important study subjects.

1. Background of Tianjin

Tianjin, one of the four municipalities directly under the central government, is the largest port city in northern China and the center of the economic area around Bohai Bay. Tianjin covers an area of 11919.7 km^2, 6.43% of which is mountainous, mainly in the north. It is located at latitude 38° 33' 57" N - 40° 14' 57" N and 116° 42 '05" E - 118° 03' 31" E, and is only 137 km away from Beijing, capital of China (figure 1). The economy of Tianjin remains with a good momentum of steady and rapid development, with a gross domestic product (GDP) of 293.188 billion CNY and per capita GDP of 28,633 CNY in 2004.

In this region, Tianjin has jurisdiction over 18 county-level divisions, which include three counties (Ninghe, Jixian and Jinghai), six urban districts (namely, Heping, Hedong, Hexi, Nankai, Hebei, Hongqiao), three coastal districts (Tanggu, Hangu, Dagang), four suburban districts (Dongli, Xiqing, Jinnan, Beichen), as well as Wuqing district and Baodi district. The total permanent population of Tianjin in 2004 was 10.2367 million, and the total registered population was 9.3255 million. Figure 2 shows the administrative divisions and population density in Tianjin.

Figure 1. Geographic Location of Tianjin City

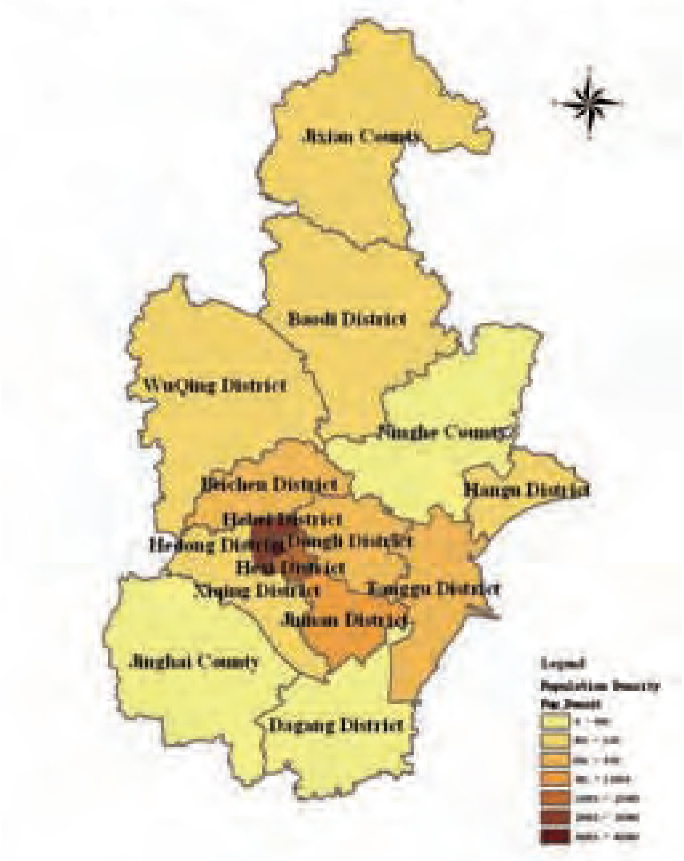

Figure 2. Administrative Divisions and Population Density of Tianjin

Tianjin has a sub-humid continental monsoon climate. The main feature of the climate is that the four seasons are clear cut, which results in a great difference in temperature and a wide variety of sceneries throughout the year. The average temperature during the year is 11.1ºC~12.5ºC, with an average highest temperature over 29ºC in July and an average lowest temperature of -6ºC. And, on average, the annual precipitation is about 550~680 mm, 75% of which is concentrated in June, July and August.

2. State of Water Resources in Tianjin

2.1 Surface Water

Surface water in Tianjin is composed of the following four parts: natural runoff, water resources entering Tianjin city, water leaving the city and entering the sea, and water transferred from other watersheds.

(1) Natural Runoff

The volume of natural runoff closely depends on the amount of precipitation within the area. The average amount of precipitation in Tianjin decreases from north to south, and is greater in the mountain areas than in the plains, ranging between 720–586 mm.

(2) Water Resources Entering the City

These water resources come from discharged water which was not used and held back by the upstream; mainly water from the reservoirs of the plain and mountain areas. The water volume depends on the precipitation, and industrial and agricultural water utilization of the upstream areas.

(3) Water Leaving the City and Entering the Sea

The water leaving Tianjin mainly enters the sea, excepting that of the Ju River coming from mountain areas, which flows to the Haizi Reservoir of Beijing. Since Tianjin is located in the lower reaches of many rivers and the number of water storage projects in Tianjin are few, the water volume entering the sea is influenced directly by the water amount from upstream areas.

(4) Water Transferring from Other Watersheds

a. Water Transferred from Luan River

Transferring water from the Luan River to Tianjin is a large water-transferring project which crosses regions. The project was completed in September 1983 and aims to lessen the pressure of water demand from the city, industry and the harbor. In the past 23 years, this project has provided more than 190 billion m^3 of water and exerted great economic benefits.

b. Water Transferred from Yellow River

Since the drought in Luan River, Yuqiao Reservoir has seriously lacked water; water transferred from Luan River could not satisfy the need of water in Tianjin, which makes it necessary to transfer water from the Yellow River. In the past years, this project effectively relieved the water crisis facing Tianjin, ensured the safety of water for use in domestic life, giving social stability, and thus accelerated the sustainable development of the economy.

Because of the geographic conditions and the uneven distribution of water resources in the different seasons and different areas of Tianjin, as well as the reservoirs constructed in the upstream area, the water amount entering Tianjin has changed a lot in the past years. Especially in the southern area of Tianjin, the water volume entering is almost zero, except in some flooding periods. In addition, the frequent occurrence of drought in Tianjin—including the periods of 1957–1958, 1960–1963, 1965–1968, 1971–1972, 1974–1976, 1980–1989, 1992–1993, and 1997–2000—is also an important factor leading to severe water shortage. However, this situation has been changed and improved in some degree by the completion of the water transfer project from Luan River to Tianjin since 1983.

2.2 Groundwater

The groundwater of Tianjin has been formed in the control of comprehensive factors such as substratum construction, the rock character of the strata, hydrology, meteorology and the erosion of transgression and regression. On the basis of the types of groundwater, there are two large hydrogeological divisions: the mountain areas with crevice water in the bedrock, and the alluvial plain area. The mountain areas can be divided in to two parts by their physiognomy, aquiferous characters, and groundwater type: that is, mountainous area (II_{1-i}) and intermountain basin area (II_{4-i}).

The alluvial plain areas can be divided into the following four parts by the mineral degree and geohydrologic condition: fully fresh groundwater area in flood-alluvial basin ($I^1_{1\text{-}i}$); fresh groundwater area in alluvial plain ($I^2_{1\text{-}i}$); brackish groundwater area in alluvial-marine plain ($I_{2\text{-}i}$); and salt groundwater area in marine plain ($I_{3\text{-}i}$). The divisions of groundwater with different mineral degree can be seen in figure 3.

The geological condition in mountain areas is relatively simple as compared with alluvial plain areas. Groundwater in mountain areas is mainly crevice water, with good natural replenishment, so this area still has exploitable potential, a dynamic balance in past years, and is mainly used for agriculture and daily life. In intermountain basin area ($II_{4\text{-}i}$), the groundwater can be still exploited to some degree for its good natural runoff conditions.

However, the geological conditions in alluvial plains are more complicated, especially in salty water areas. The artesian aquifer water in this region can be divided into five categories, from top to bottom, namely artesian aquifer I (with a depth of aquifers of 20–30 m), salty artesian aquifer S (40–220 m below the ground level from north to the southeast, only in salty water areas), artesian aquifer II (180–228 m from north to south of Tianjin), artesian aquifer III (290–315 m), and artesian aquifer IV (370–429 m). Because of the central industries and a shortage of surface water supply, the groundwater in fresh groundwater areas in the alluvial plain ($I^2_{1\text{-}i}$) has already been overexploited. While the brackish groundwater area in the alluvial-marine plain ($I_{2\text{-}i}$), the salt groundwater area in marine plain ($I_{3\text{-}i}$), and the brackish or salt water in the shallow aquifer have been exploited on a rather small scale for their high mineral degree and salt concentration, the fresh groundwater in deep artesian aquifer (in artesian aquifer II and III) has been overexploited as seriously as that of the alluvial plain to meet the needs of social economic development, thus inducing geological problems.

In Tianjin, groundwater abstraction started at the beginning of the twentieth century, with the first motor well dug in Tanggu in 1907. More and more groundwater was exploited accompanying the development of industry and agriculture, as well as city expansion. In 1967, the exploited volume reached 70 million m^3, with 60% focused on the artesian aquifer II. During that period, the geological environmental problems came into appearance with the overexploitation of artesian aquifer II. Groundwater exploitation climbed and peaked in the years 1965, 1968, 1972, 1989 and 1999 because of bad drought. Surface water decreased, thus groundwater was overexploited. Since the water transferred from Luan River came into urban areas and Tanggu District in 1983, the government took steps toward exploitation control with the plan of subsidence control that was put into practice. In the same year the government took some measures, and some water saving projects boomed, which has resulted in a decreasing trend in groundwater abstraction since then. But groundwater exploitation is often affected by precipitation, so the exploited volume may have increased in some years, but the average abstracted volume was under control.

Figure 3. Groundwater Resource Divisions in Tianjin
Source: Plan of Groundwater Source Exploitation in Tianjin, 1997/1998

2.3 Water Supply and Utilization in Tianjin

For many years, groundwater and surface water have been the main sources of water, with groundwater accounting for about 30% of the total water supply (figure 4). Two other unconventional water resources, reclaimed water and desalted water, also play an important role in Tianjin's water supply. The total volume of water used was 2.206 billion m^3. The largest water consumption in Tianjin is for agriculture, accounting for 55.2% of the total; second is industrial production, while the rest of the water is mainly used for daily life and landscape, as shown in figure 5.

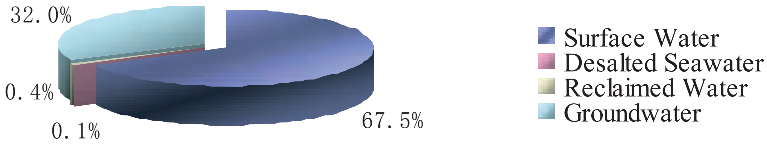

Figure 4. Proportion of Water Supply by Water Resources in 2004
Source: Report on Environmental Quality of Tianjin, 2001-2005

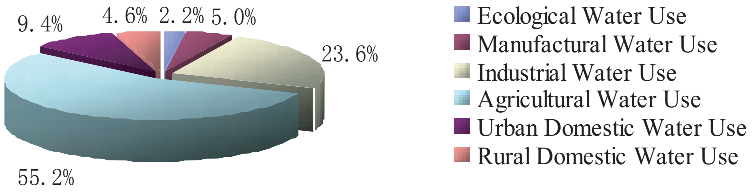

Figure 5. Proportions of All Kinds of Water Use in 2004
Source: Report on Environmental Quality of Tianjin, 2001-2005

3. *Issues and Discussion on Groundwater in Tianjin*

3.1 Dynamic Characteristics of Groundwater Level

Groundwater level varies significantly in the different areas of Tianjin, each with their own degree of water exploitation. In all of the freshwater areas, for instance, there is still a balance between exploitation and yield, and the groundwater level has not much changed over the years. In contrast, the water table in the saltwater regions has continually dropped because of the severe shortage of surface water resources and its heavier demand on groundwater. This overexploitation has resulted in the creation of several huge tunnels under urban areas in the districts of Tanggu, Hangu, Dagang, Wuqing, and Jinghai County, where the deep fresh groundwater level is more than 30 m below the ground, and the deepest is down more than 100 m. Figures 6 and 7 show the changes of groundwater level in Tianjin.

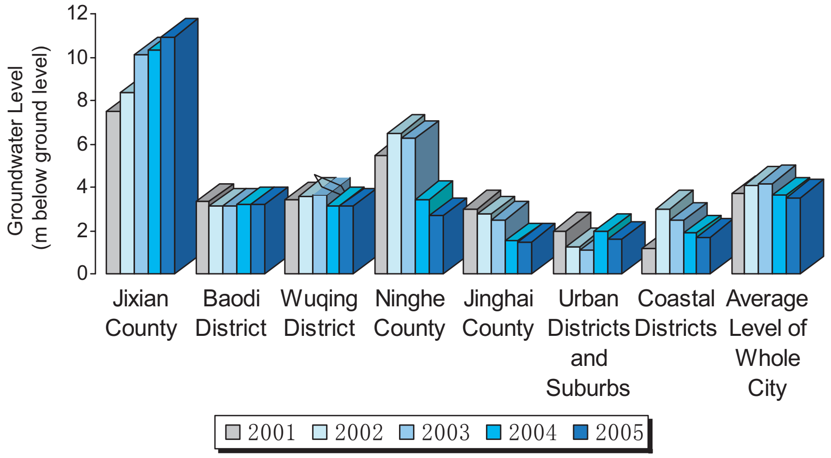

Figure 6. Change of Shallow Groundwater Level in Tianjin
Source: Report on Environmental Quality of Tianjin (2001-2005)

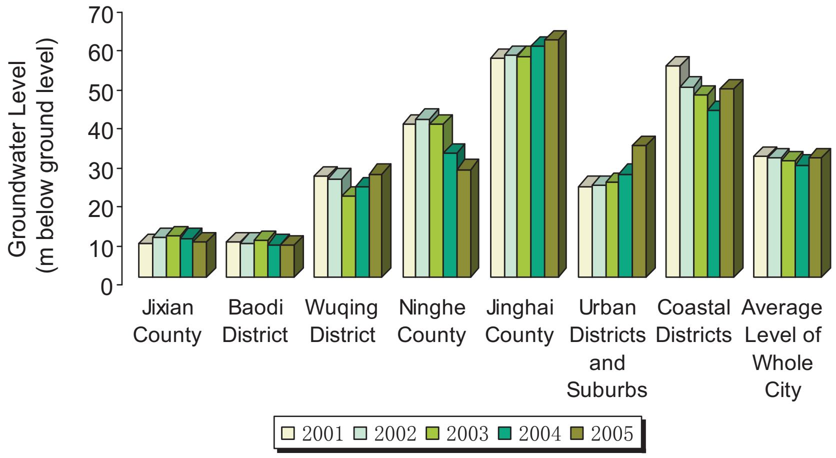

Figure 7. Change of Groundwater Level in Artesian Aquifer II in Tianjin
Source: Report on Environmental Quality of Tianjin (2001-2005)

3.2 Groundwater Level and Land Subsidence

Groundwater resources are not evenly distributed in Tianjin. All fresh groundwater lies in the northern areas and is abundant, but there is little industry and the population density is very low. The saline water areas in the middle-south and southeast, on the other hand, have high population densities and centralized industrial production, which has resulted in a shortage of water resources.

The increase in the water demands of the residential, industrial and part of the agricultural production sector has resulted in a continuous drop in groundwater levels. Looking at the average annual use of groundwater in each district or county from 1991 to 2002, groundwater exploitation already exceeded available groundwater volume in all districts/counties except for Jixian, Ninghe, Jinghai, and Baodi (figure 8).

It has been proven through practice that groundwater exploitation in the long term is the main factor leading to land subsidence. The significant use of groundwater has led to the problem of surface subsidence, especially in the southern part of Tianjin, where the deeper aquifer (which is hard to access and recharge) continues to be overexploited for residential, industrial and agricultural purposes because of the lack of surface water. Furthermore, statistical data shows that a total affected area of about 7,300 km^2 has suffered from the problem of land subsidence, to differing degrees. Especially in urban areas, the districts of Tanggu, Hangu, Dagang, and industrial areas downstream of the Haihe River, some centers of land subsidence have formed already (figure 9). Some statistical data shows that the biggest cumulative

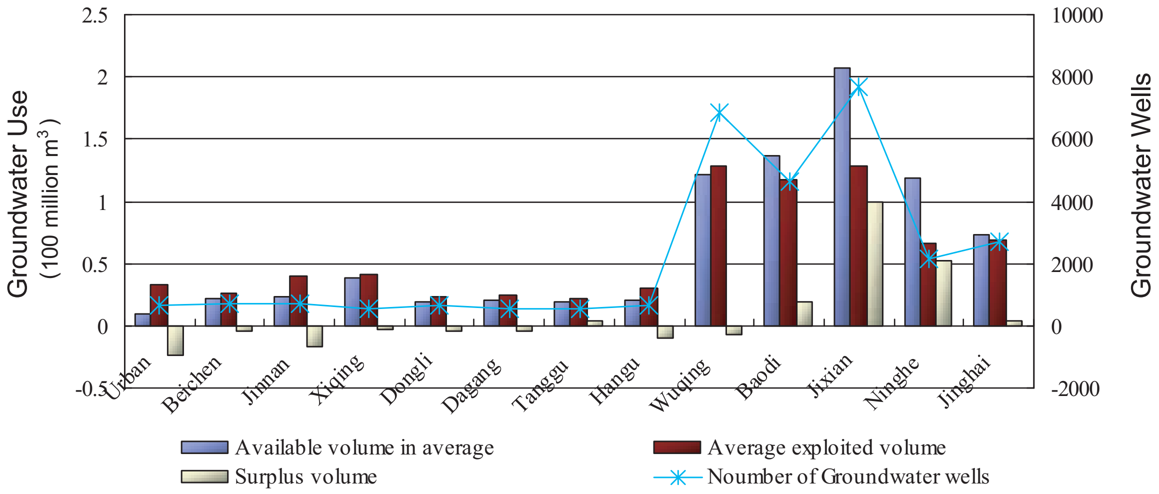

Figure 8. Average Volume of Groundwater Used from 1991 to 2002 and Groundwater Wells in Tianjin by District

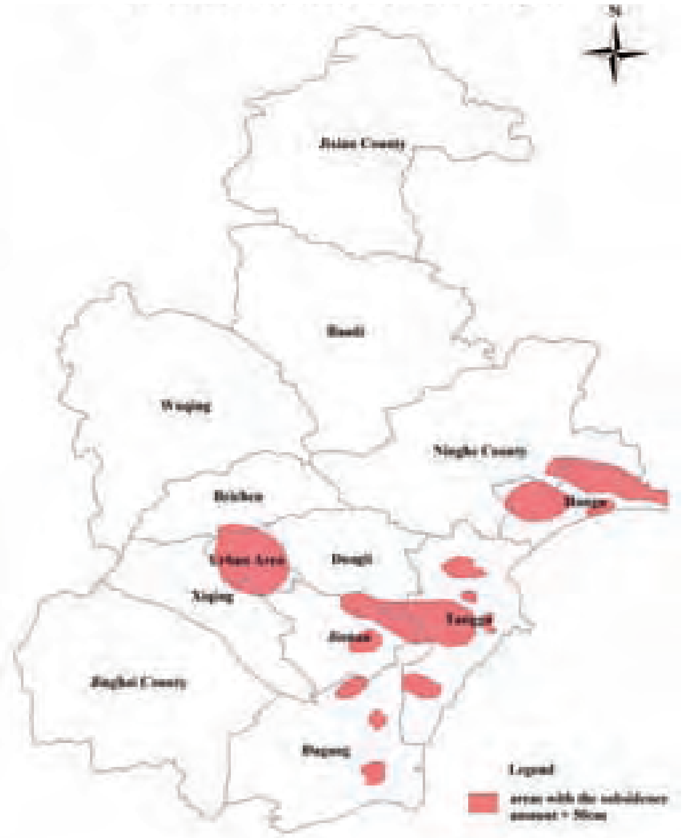

Figure 9. Centers of Land Subsidence in Tianjin Greater than 50 Centimeters
Source: "Study Report on Conceptual Planning for the Coustruction of Ecological city of Tianji", 2005, Unpublished.

amount of land subsidence from 1959 to 1994 in Tanggu subsidence center was about 3m, and that of Hangu district is about 2.6 m.

3.3 Groundwater Pollution

Groundwater quality in Tianjin is not the same in each area. In the northern part of the plain area (the districts of Jixian, Baodi, and Ninghe) it is relatively good and can meet category III (five categories in total, category V being the worst) of the national groundwater standard on the whole, except for the fluorine level exceeding the prescribed limit. Meanwhile, in the southern and eastern area of the plain area (Wuqing urban district and suburban districts, Jinghai costal area), water quality is not good. About 10-30% of samples do not comply with the groundwater quality standard for mineral degree, pH, chlorine, nitrite, and sulphate.

Among the parameters of groundwater quality, the concentration of fluorine is the one to which special attention should be paid. Fluorine is distributed widely in groundwater in Tianjin. Many people in certain areas of Tianjin have suffered serious diseases caused by drinking water with a high concentration of fluorine for a long time. Recently this situation has improved through measures taken for fluorine removal. There are many ways for removing fluorine from groundwater in Tianjin. For instance, in Dagang District, two methods were used: one was to look for groundwater wells with low fluorine levels and setting up fluorine removal equipment (used for both large scale and family life). The second way was to remove fluorine by coagulation sedimentation, adsorption filtration, electrodialysis, membrane, etc. At present people in these areas are not suffering from the diseases any more.

4. Status Quo of Reclaimed Water in Tianjin

So-called "reclaimed water" is the kind of water that comes from wastewater, which can meet a certain water quality standard and be used for industrial production, agriculture irrigation, daily life, etc., after being treated by the secondary or deep treatment process of wastewater. When considering the sustainable use of water in Tianjin, reclaimed water has the most potential as a beneficial alterative water resource when compared to groundwater. Reclaimed water can, for example, reduce the volume of wastewater drained to rivers; release the pressure on the water drainage system in the city; and is very good in terms of environmental protection. In Tianjin, an average amount of 0.5–0.6 billion tons of wastewater is discharged every year. It is a promising and stable source for water reuse. And, from the perspective of technology, wastewater treatment technologies have proved to be quite feasible. Wastewater can be treated to meet any kind of water needs through the conventional methods of in-depth water treatment technology include filtering, micro filtering (MF), Reverse Osmosis (RO), etc. In addition, the utilization of reclaimed water can avoid the long-distance water transmission needed for other water transfer projects, thus the cost of the reclaimed water is reduced. Also, the scale of regenerating and reutilizing wastewater can be very flexible according to the situation. Large-scale plants for water regeneration can be built on the outskirts of the city, and small-scale plants or systematic equipment dealing with wastewater can be also built in the residence communities and public buildings.

4.1 Pilot examples of Reclaimed Water Use in Tianjin

Relative research on wastewater reuse has been undertaken since the 1980s in Tianjin, and a great deal of progress has been made in this field. Although there is no large-scale utilization of reclaimed water in Tianjin at present, systems of wastewater recycling and reutilization have been built in many places, of particular note being the Jizhuangzi reclaimed water use project and the reclaimed water project in the Technologic-Economic Development Area (TEDA)[1] of Tianjin. Here below we will introduce the two projects in detail:

(1) Jizhuangzi Reclaimed Water Use Project

Jizhuangzi reclaimed water use project, the project with the broadest use and most advanced techniques among the pilot projects in China, includes a wastewater treatment plant, a reclaimed water plant and a water transportation network.

Jizhuangzi wastewater treatment plant, the first large-scale urban wastewater treatment plant in China, was put into service in 1984 with a design scale of 26,000 m^3 per day, and mainly treats wastewater from Heping District, Hexi District, and Nankai District. In this plant, a technique called Anaerobic-Oxic (A/O) dephosphorization craft is used. After being treated by the primary treatment, such as grit and sedimentation, the wastewater enters an activated sludge reactor. The former part of this tank is anaerobic and the later is oxic, where the phosphor compound will be removed by large proportions and the wastewater can be purified. Then the effluent will be transported to Jizhuangzi reclaimed water plant.

In the reclaimed water plant, there are two different kinds of treatment process. The first one is the traditional process designed for industrial use which contains the processes of coagulation, sedimentation, ordinary filtration and disinfection. The design scale of the traditional treatment process is about 30,000 m^3/day, and the reclaimed water will be used for industrial cooling or industrial production, such as in paper mills or at the thermal power plant in Chentangzhuang industrial area. Another treatment technique is CMF+O_3. The process of this technique is almost the same as that of the traditional technique, but introduces an advanced filtration called continuous micro-filtration (CMF) that is adopted to replace the ordinary filtration and a process of ozone oxidation between CMF and disinfection. That is the very reason the water quality is much better than that of the traditional work process. In this project, the design scale of the new treatment process is about 30,000 m^3/day, whose effluent water will be transferred to many resident areas such as Meijiang, Meijiangnan, Weinanwa, etc., and be used for toilet washing, greenbelt watering, landscape and so on.

(2) Reclaimed Water Use Project in TEDA

TEDA wastewater treatment plant was put into service in December 1992 and its design scale is 100,000 m^3/day. In

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[1] The establishment of Tianjin Economic and Technological Development Area (TEDA) was given government approval on December 6, 1984. One of the country's first state-class development areas, TEDA has developed into one of the country's most influential hotbeds for high-tech and new industries. Notably, it has its own policies in this zone and several privileges in economic development.

this plant, a technique of DAT-IAT (Demand Aeration Tank - Intermittent Aeration Tank) is used to treat wastewater. In general, wastewater intermittently feeds into the DAT, then the effluent from the DAT enters the IAT continuously and completes other working procedures including reaction and sedimentation.

In the TEDA reclaimed water plant, which is located beside the TEDA wastewater treatment plant, an international advanced in-deep water treatment process called "double-membrane" is used, with a purified technique of continuous micro-filtration (CMF) in water pretreatment, and a desalination technique of RO in the main treatment process. In this process, matter—including SS, bacteria, and organisms whose diameter is larger than that of the membrane—will be held up, and the water is purified. The total scale of the TEDA RWP is 30,000 m^3/day, of which 10,000 m^3/day of the entire treated water is used for industrial production and daily life use, and 20,000 m^3/day, being treated only by CMF, is used for city landscape and green watering.

4.2 Quality standards for different application of reclaimed water

With the rapid development of wastewater reuse in China, associated standards were issued by the national government and taken into effect gradually in order to guide the reasonable use of reclaimed water. It is stated that the quality of reclaimed water must meet different national criteria depending on its special utilization. For instance, when reclaimed water is used for agriculture, the items in the "Standard for Irrigation Water Quality" (GB5084-92) should be taken into account; when it is used for fishery water, the standard of the "Water Quality Standard for Fisheries" (GB 11607-89) should be met; and for scenic water, the "Environmental Quality Standard for Surface Water" (GB 3838-2000) should be met.

And now, for the purpose of carrying out the policy of "water pollution prevention and control, water resources exploitation and utilization"; improving the efficiency of urban wastewater reuse; and promoting the proper utilization of water resources, a standard set called "The Reuse of Urban Recycling Water" has been developed, of which three new national criteria on the reuse of urban recycling water were specially issued by the Standardization Administration of the People's Republic of China (SAC) in December 2001 and have been in effect since 1 May 2003. Table 2 shows some standards about reclaimed water use and some criteria of the relative standards; and Table 3 shows relevant standards which will be put forward in the near future.

Table 1. Water Quality Standards for Different Applications of Reclaimed Water

Reclaimed Water (RW) for different Uses	Standards of Water Quality
RW used for non-potable household consumption, including toilet washing, garden greening, car washing, etc.	• "Water Quality Standard for Non-potable Household Consumption" (CJ/T 48-1999) • "The Reuse of Urban Recycling Water—Water Quality Standard for Urban Miscellaneous Water Consumption" (GB/T 18920-2002)
RW used for Scenery and Recreation	• "Water Quality Standard for Scenery and Recreation Area" (GB 12941-91) • "The Reuse of Urban Recycling Water—Water Quality Standard for Scenic Environment Use" (GB/T 18921-2002)
RW used as cooling water	• Recommend Water Quality Criterion of Reclaimed Water Used as Industrial Cooling Water in the "Urban Wastewater Reuse Design Code" (CECS 61:94)
RW used for groundwater recharge	• "The Reuse of Urban Recycling Water—Water Quality Standard for Groundwater Recharge" (GB/T 19772-2005)
RW used for agriculture irrigation	• "Standard for Irrigation Water Quality" (GB 5084-92)
RW used for fishery	• "Water Quality Standard for Fisheries" (GB 11607-89)

Table 2. Reclaimed Water Quality Standards to be Issued

Reclaimed Water for different Use	Standards of Water Quality
RW used for agriculture irrigation	• "The Reuse of Urban Recycling Water—Water Quality Standard for Agriculture Irrigation"
RW used for industry	• "The Reuse of Urban Recycling Water—Water Quality Standard for Industry"
RW used as supplementary water	• "The Reuse of Urban Recycling Water—Water Quality Standard for Supplementary Water"

5. Water Management Mechanism and Associated Policies in Tianjin

5.1 Institution framework

The current institutional framework for water resources management in China consists of the following levels: national, river basin, and regional. In some places, they are interconnected. The Ministry of Water Resources (MWR) is the main organization under the State Council in charge of the integrated management of water resources. This department, however, has not been given all of the related responsibilities; several other ministries join the national effort for water resources management and share some of them. These include the Ministry of Construction (MC), the National Environment Protection Agency (NEPA), the Ministry of Land and Resources (MLR), and the State Development Planning Commission (SDPC). Each of them is in charge of different aspects and has different responsibilities.

In Tianjin, a majority of water affairs (including groundwater) are managed by the Tianjin Water Conservancy Bureau, which is responsible for water resources management and water saving, such as providing comprehensive management for water resources; drawing up long-term water supply plans and integrating them into a municipal economic and social development plan; and monitoring, evaluating and managing water resources within the municipality.

5.2 Associated water management policies and their effects

Measures for water management can be found in various water resource laws and regulations both at the national level and local level. Regarding their different effects, some pivotal laws/regulations are listed as follows:

(1) Water Right

"Water Law of PRC" (2002) : The "*Water law of PRC*" was enacted on 10 October 2002 and aimed to exploit, use, save and protect water resources reasonably; to control water pollution; and to realize sustainable water use to meet the needs of the social economic development of the country. In this law, it was definitely defined that:

- the proprietary rights of water resources belong to the nation;
- the legal rights and interests of organizations and individuals that exploit and utilize water resources should be protected according to the law. Also, organizations and individuals have an obligation to protect water resources;
- the nation possesses the proprietary rights of water resources. Any organization or individual involved in exploitation and utilization directly from river, lake or groundwater resources is required to apply for a license and pay a certain amount of water resource charge, except in cases of rather small amounts of water being used in daily life or livestock feeding;
- water management institutes should be set up in important river or lake basins to carry out their duties in water management and supervision;
- measures for water saving should be put into effect in industrial production, agriculture irrigation, water transfer and domestic water consumption.

In addition, the "*Management Regulation for Water-taking Permission and Water Resource Fee Charging*" issued by the State Council has been in effect since 15 April 2006. This regulation not only gave more detailed information about the application process and allowed an amount of water-taking, it also stated the principles of water resource fee charging and the special use of those fees for water conservancy projects. On the local level, associated regulations about water-taking permission had also been issued to realize the better implementation of the national water management laws.

(2) Water Pollution Control

"Water Pollution Control Law of PRC" (1984) : This law is suitable for water pollution control in all surface water (including rivers, water canals, and reservoirs, but not the seas) and groundwater in the territory of PRC. It regulated that:

- all organizations and individuals have the responsibility to protect our water environment, and have the right to supervise or impeach polluting behaviors to the water;
- water quality standards should be enforced on wastewater discharge;
- EIA or SEA should be done in the establishment of associated projects;

- wastewater discharge fees should be collected and be used in a reasonable way;
- wastewater discharge is prohibited in special places such as water resource places, etc;
- water quality monitoring should be carried out regularly.

In Tianjin, in addition to the national laws, some local regulations were carried out by the local government. For instance, “Measures for Water Pollution Control in Tianjin” (2003), “Measures for Protecting Water Transferred from Yellow River to Tianjin” (2002), “Regulation of Water Pollution Control of Water Transferred from Luan River” (2002) stated a great number of special measures to protect water resources from various types of pollution in the process of water exploitation, utilization and transportation.

(3) Water Charge/fee

“Management Rules for the Charging of Groundwater resource fee in Tianjin” (1987) : It was taken into effect on 1 June 1987 and stated that:

i. groundwater used for agriculture irrigation and daily drinking in the country is temporarily free;
ii. a groundwater fee should be added if the abstracted amount is out of the plan;
iii. those fees should be charged by Tianjin Water Conservancy Bureau, and used for groundwater management, water transfer projects, science study associated with the groundwater.

“Notification of Adjusting the Standard of Groundwater Resource Fee” (2002) : This rule was issued by Tianjin financial bureau and Tianjin price bureau on 8 November 2002. It stated that: the price of groundwater resource fees should be increased to 1.3 CNY/m^3 for those water users without a tap water supply or 1.9 CNY/m^3 in the areas which can access the tap water supply system, from the previous 0.5 CNY/m^3.

“Notification from Tianjin Price Bureau about the adjustment of the water fee” (2007) : This notification is not a single one but a set of files. It was revised in 2002, 2005 and 2007 and is issued by the Tianjin Price Bureau. In the newest file, taken into effect on 1 March 2007, it is stated that:

i. the charge of the water supplied to the water companies is increased to 1.03 CNY/m^3;
ii. the selling price of tap water from water companies is composed of four parts, namely, basic water fee, wastewater treatment fee, water resources fee and water added fee for urban public utility. Within these, the water resources fee for residential use is 0.25 CNY/m^3, while for others it is 1.03 CNY/m^3 ; wastewater treatment fee for residential use is 0.80 CNY/m^3, while it is 1.20 CNY for others; and the water added fee used for urban public utilities accounts for 10% of the total tap water fee.
iii. the fee for tap water used for daily life is 3.40 CNY/m^3 ; 6.20 CNY/m^3 for administrative agencies or social groups, industry, business, transportation, construction and hotels; while 20.60 CNY/m^3 for special sectors (e.g. chemical industry);
iv. the water resources fee from the tap water fee is used for the south-to-north water transfer project fund.

“Notification about the sell price of the reclaimed water from Jizhuangzi reclaimed water plant” (2003) : This rule has been in effect since 1 November 2003. According to this notice, with a target to encourage reclaimed water use and based on the operating conditions of Jizhuangzi reclaimed water plant, the sell price of the reclaimed water from Jizhuangzi RWP is set as follows (see table 3). It is much cheaper compared to the tap water price of 2.9 CNY/m^3.

Table 3. Sell Prices of Reclaimed Water from Jizhuangzi Reclaimed Water Plant

Category	Price (CNY/m^3)
RW used for residents	1.10
RW used for school, hospital, kindergarten, etc.	1.20
RW used for industrial production	1.30
RW used for landscape, watering, road washing, etc.	1.50
RW used for car washing, building construction, etc.	1.50

Source: Notification about the selling of price of the reclaimed water from Jizhuaugzi reclaimed water plaut.
Note: The Notification became ettective from Nov, 2003.

According to the "Notification from State Council about advancing the adjustment of water price and promoting water saving" issued by China State Council on 9 April 2004, the price of reclaimed water should be set rationally. This notification states that a privileged price for electricity and tax should be granted to reclaimed water production enterprises.

(4) Groundwater Abstraction

In some plans such as the "*Plan of Groundwater Source Exploitation in Tianjin*" (1997), it was proposed that:

- in the northern mountainous area with good replenishment and exploitable potential, groundwater abstraction can be increased by some appropriate degree;
- in the southern part of Tianjin with shallow salt groundwater aquifer, such as the urban areas, Hangu district, and Tanggu district, due to sensitivity in land subsidence and stable surface water supply, deep groundwater is forbidden to be further abstracted;
- in some areas with alternative water resources and serious land subsidence, the abstraction of groundwater should be reduced by 5% year by year;
- in addition to the limitation of groundwater exploitation, other measures should be also taken including water saving, water transfer, water reuse, groundwater recharge, etc.

(5) Reclaimed Water Use

Considering the serious water shortage in Tianjin, the city government attached great importance to the development of the reclaimed water use project.

For the purpose of encouraging reclaimed water use, the "*Management Regulations on Water Drainage and Reclaimed Water Use*" issued by the People's Congress of Tianjin was taken into effect on 1 December 2003; the "*Rules of Constructing Reclaimed Water Supply System in Residential Area of Tianjin*" and the "*Technologic Rules for Reclaimed Water Supply System in Residential Area of Tianjin*" were proposed by Tianjin Construction Committee, which aims to regulate the water users who must use reclaimed water; and state that newly constructed buildings must build their own special pipe for reclaimed water or their own water reuse system.

The "*Plan of the Reclaimed Water Use in Urban Areas of Tianjin*" (2000), and "*Overall Plan for Reclaimed Water Irrigation in Agriculture*" (not issued) proposed a particular plan about the reclaimed water used both in urban areas and rural areas, as well as the future construction of reclaimed water plants and pipe networks.

(6) Others

"Temporary Measures of Groundwater Management in Tianjin" (1987) : In 1987, the Tianjin government enacted the "*Temporary Measures of Groundwater Management in Tianjin*", making an active effect to exploit and utilize water resources rationally, and to prevent ground subsidence. So far, the municipal government has listed the regulations of "*Administrative Measures of the Groundwater Resources in Tianjin*" in the government's legislation program in 2004, to thereby perfect the existing "*Temporary Measures of Groundwater Management in Tianjin*" and to manage Tianjin's groundwater resources in a much better way.

"Water Saving Regulations of Tianjin" (2002) : On 19 December 2002, the Standing Committee of the Tianjin People's Congress passed the "*Water Saving Regulations of Tianjin*", which stipulated that 'a management method of total control on the amount of water use should be implemented in Tianjin', and a 'water reusing system and other water saving measures such as multiple use of water should be adopted and carried out'.

"The 11th Five-Year Plan of Tianjin to Establish a Water-saving Society" (2005) : "*The 11th Five-Year Plan of Tianjin to Establish a Water-saving Society*" (2005) defined the meaning of water saving, which is: to improve the efficiency of water resources utilization by reducing inefficiency and low efficiency of water utilization; to improve the economic and ecological outputs of water utilization by optimizing and adjusting the industry structure and scientific allocation of water resources; to exploit and utilize alternative water resources to reduce the one-off volume of freshwater used; to reduce water demand by virtual water trade. It also proposed a prospect about the different application of various alternative water resources in Tianjin.

6. Challenges and Recommendations to Sustainable Water Management in Tianjin

6.1 Management Mechanisms

Presently in Tianjin, in addition to the Water Conservancy Bureau, water is also managed by many other authorities including the Construction Committee, the Municipal Bureau, and the Geology and Mineral Resources Bureau. The Water Conservancy Bureau takes charge of the water supply and drainage; the Water Conservancy Bureau, and the Geology and Mineral Resources Bureau administrate groundwater according to region and water temperature; the Construction Committee is responsible for the control and corresponding work of ground subsidence caused by groundwater exploitation; and reclaimed water use is under the control of the Municipal Engineering Bureau. They failed to reach an accordant management in water affairs, and every unit conducts their own management according to their own policies. As a result, the whole situation falls into disorder and it is very difficult to achieve the harmonized allocation and development of the water resources as a whole.

Considering the decentralized management of water resources in Tianjin, a kind of 'team to guide the work of water resources utilization in Tianjin' should be set up by the municipal government to: manage and allocate the utilization of the water resources by integrated planning; be in charge of the examination and operation of the projects, the water fees and water quality supervision; manage the facilities and pipe networks; develop relative policies or regulations concerning water use and water quality; establish associated plans for emergent situations; and other relevant issues. Also, a system of mediating water affairs should also be established as soon as possible.

6.2 Water Price and Economic Stimulating Policy

In Tianjin, the price of tap water has been rising year by year. In the past, the surface water price in Tianjin was about 1.0 CNY/ton, and the price of groundwater was about 0.5 CNY/ton, while the price of reclaimed water was 1.3 CNY/ton, on average. As a result, business companies would like to use the surface water and groundwater rather than reclaimed water. To protect groundwater resources and control land subsidence, the Tianjin municipal government adjusted its standard pricing system after 2002, and the price was set at 1.90 CNY/m^3 and 1.30 CNY/m^3 in areas without tap water service. However, there is no information available yet to show if the new pricing has affected market mechanisms to allocate groundwater resources wisely according to the present socioeconomic conditions in Tianjin. Further research is needed to validate its effectiveness in moving towards sustainable groundwater management.

In addition, because of the early stage of reclaimed water use, there are not that many relative fostering policies. It is regulated so that the section of city water supply is charged a value-added tax of 6%, but as reclaimed water does not belong to this category, a tax of 17% is used for reclaimed water, which leads to the weak competitive power of this industry. For the purpose of quickening the utilization of reclaimed water, a rational price system must be formed to demonstrate the price advantage of reclaimed water. Prices of tap water and well water will be boosted gradually to extend the price gap between reclaimed water and other water resources. And, particular policy supports should be offered to reclaimed water companies concerning credit, revenue and other aspects. The government should offer appropriate allowance to those reclaimed water companies who cannot sell the water at its cost temporarily, and necessary allowance should be granted to the use of reclaimed water in agriculture. For those companies which use reclaimed water according to the relevant regulations, they should be awarded for saving water and treated as environment-protecting companies, and their construction and operation fees should also be remitted and cut down.

6.3 Reduce Groundwater Abstraction and Pollution

As mentioned above, Tianjin has suffered from land subsidence since the 1980s. It has been proven that reducing groundwater exploitation is one of the most effective measures in controlling land subsidence. In Tianjin, according to the degree of groundwater exploited and land subsidence, groundwater exploitation is forbidden entirely in some places; and for others, groundwater exploitation should be reduced gradually or placed under strict controls. Also, adjusting the aquifer of groundwater exploited and groundwater recharge are also good methods to release the pressure of land

subsidence in Tianjin. However, how to solve the problem of groundwater over-abstraction in drought years with low precipitation and small natural runoff is still a big question and challenge to the Tianjin government.
Pollution in groundwater mainly comes from polluted surface water and wastewater, pesticides, and fertilizer distributors used in agriculture irrigation, which should all be strictly controlled in the future. Still, perfecting the existing water monitoring system, enhancing the monitoring of groundwater level, quality, and quantity in different aquifers is also a good suggestion to improve Tianjin's groundwater management.

6.4 Promote the Use of Reclaimed Water

(1) Infrastructure Constructions of Reclaimed Water
In Tianjin, there are several reclaimed water use projects, which can provide a large volume of reclaimed water. However, because of the faultiness of the water pipe network, the reclaimed water cannot be transferred to other places, so it has to discharge into the drainage system of the city and cannot be reused.

In order to solve these problems many measures can be undertaken. For instance, pipe network construction must be considered in the design of the overall road system and development of residential communities in the city. If pipes for reclaimed water were buried first, the future destruction of the roads for setting the pipes could be avoided. Watercourses used to transfer reclaimed water should be maintained properly to make sure that water can be drained smoothly; and the sullage in the bottom of river ways should be cleaned regularly to avoid secondary pollution during the reclaimed water transfer.

(2) Supporting of Science and Technology
At present, to realize the wide use of reclaimed water, there is still a lack of support from mature techniques. Water quality standards, examination, monitoring and other relevant technical problems have not been standardized either. There exist a lot of questions, for example regarding what crops can be irrigated with reclaimed water; how to design a program to achieve safe irrigation; what the irrigation regulations should be; and how to assess the impacts of reclaimed water irrigation on the soil, groundwater and crops.

The development of utilization of reclaimed water must depend on the development of science and technology. When reclaimed water is used in agriculture, ecology, municipal works and industry, attention should be paid to the study of the water purification, water stability and the insurance, management, techniques related to the facilities. In addition, model projects of utilizing reclaimed water in agriculture should be built as soon as possible to make clear what crops can be irrigated by reclaimed water, how to design a safe irrigation process, how to set the irrigation regulations and how to assess the ecological influence of reclaimed water irrigation on soil, groundwater, crops and how to regulate the techniques of water storage. At the same time, analysis and assessment of the benefits and risks should be made in time, for effective control and management. In this way, safety concerning the utilization of reclaimed water will be improved and ensured.

6.5 Supervision System and Public Participation

It is necessary to make the public realize the severe situation of water scarcity and the necessity of water saving. As a result, various activities have been held in schools, communities and companies to raise public awareness. And, in order to realize effective and justified water management in Tianjin, an effective supervision system, not only including the government and institutes at different levels but also involving the participation of the public, should be set together with the integrated management team of water resources.

6.6 Alternative Water Resources

Instead of abstracting groundwater, there are some other alterative water resources which can partly compensate for the water shortage in Tianjin. Listed below is detailed information about the alternative water resources in Tianjin:

(1) South to North Water Transfer Project

The south-to-north water transfer project consists of three water-transferring lines and Tianjin will benefit from the east route and middle route of this project. This project is scheduled to be completed by 2020, and by then, according to the "*The 11th Five-Year Plan of Tianjin to Establish a Water-saving Society*", 400 million m^3 of water will be transferred to Tianjin every year, all of which will be used for urban areas.

(2) Brackish Water

The so-called "saline water" refers to water with a mineral degree of more than 2g/l. According to the mineral degree, saline water can be divided into brackish water (2-3g/l), semi-saline water (3-5g/l), salt-water (5-10g/l) and brine (>50g/l). Brackish water can be used in long-term agricultural irrigation, especially during the drought period in spring. After salt-water is mixed with freshwater, it also can be used as irrigation water if the salt contained in the mixed water is less than 5g/l.

In Tianjin, large scale applications of brackish water irrigation have not started, but scientific research has been going on since the 1970s. Currently, in the Dagang District of Tianjin, "double pipes" are used for the water supply from Luan River and groundwater. Brackish groundwater and water with a high concentration of fluorine is used for daily life use (except for as drinking water) instead of fresh water. Also, pilot research of brackish water irrigation has been started in the western Jinghai District, in which an area of about 16,667 m^2 (in small-scale) was used for brackish water irrigation experiments, and another area of 1,000,005 m^2 was used for the enlarged scale experiment (bench scale research). In this study, the effect of brackish water irrigation for winter wheat was tested and primary progress was made in the past years. In addition, in the eastern Jinghai District, a partial wetland can be formed through a controlling of land subsidence by the proper exploitation of shallow groundwater, which will improve the local ecologic environment and bring large economic and environmental benefits.

(3) Desalted Seawater

Tianjin has been leading the field in the research of seawater circulating cooling technology and seawater exploitation in China. The utilization of seawater plays a very important role in the exploitation of non-traditional water sources.

At present, there are two successful projects utilizing seawater directly and one seawater desalination project in Tianjin. One project utilizing seawater directly is the seawater once-through cooling process of the Electricity Plant in the north Dagang District. Another project is the Seawater Purifying Plant in Tanggu District. These practical experiences can be extended to other costal area of Tianjin. However, the benefits of seawater desalination are not certain due to its relatively high cost compared to other water resources.

7. Conclusions and Prospects

Over the past years, water shortages have become a common occurrence in Tianjin due to its geographic conditions and the uneven distribution of water resources in different areas, as well as in different seasons. To meet the needs of economic development and daily life use, a large amount of groundwater was exploited in the past, which has led to severe land subsidence in some areas of Tianjin, especially in the south. However, thanks to the strict limitation of groundwater exploitation, as well as the completion of the water transfer project from Luan River to Tianjin in 1983, the serious pressure on water supply has been released greatly, and the groundwater level has also ascended. Still, this phenomenon of land subsidence is also a big problem in Tianjin's sustainable water management and more attention should be paid as to how to solve this problem through further scientific research.

The development and utilization of alternative water resources is also a good method to realize sustainable water utilization in Tianjin. Since the 1980s, relative research about wastewater reuse has been done in Tianjin. Some pilot reclaimed water use projects have been put into effect and provide water in the wide use of reclaimed water for urban miscellaneous consumption and industrial production. However, wastewater reuse for agriculture should be increased in the future. Thus, the exploitation of groundwater used for irrigation could be reduced, which would be good to control land subsidence.

Although much progress has been made in the water management of Tianjin, and many policies and regulations have taken into effect, the challenge of unseasonable water management mechanisms should be improved by speeding the pace of popularizing reclaimed water, improving the efficiency of the scientific use of all water resources, as well as forming an integrated water management system. In addition, an effective supervision and monitoring system in Tianjin will be an important subject that needs to be studied in the near future.

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CHAPTER 3-5

The Study of the Management of Groundwater Resources in Sri Lanka

1. Background to the Study Area

1.1 Introduction

This investigation, “The Study of Management of Groundwater Resources in Sri Lanka,” is part of the Sustainable Water Management Policy Project, a collaboration between the Institute for Global Environmental Strategies (IGES) in Hayama, Japan and the Department of Civil Engineering of the University of Peradeniya, in Peradeniya, Sri Lanka. The study mainly focuses on groundwater and its alternative water source management in two urban centers in Sri Lanka. In addition, the study briefly discusses groundwater use in agriculture and the impacts of the tsunami on the coastal groundwater reserve.

1.2 Study Area

The two main study areas selected for this analysis are the urban and suburban areas of Colombo and the urban and suburban areas of Kandy (figure 1). Groundwater use in agriculture is discussed through the agro-wells (wells that are used for agricultural purposes) in the northwestern regions, while the impact from the tsunami is discussed through the coastal groundwater resources (figure 1).

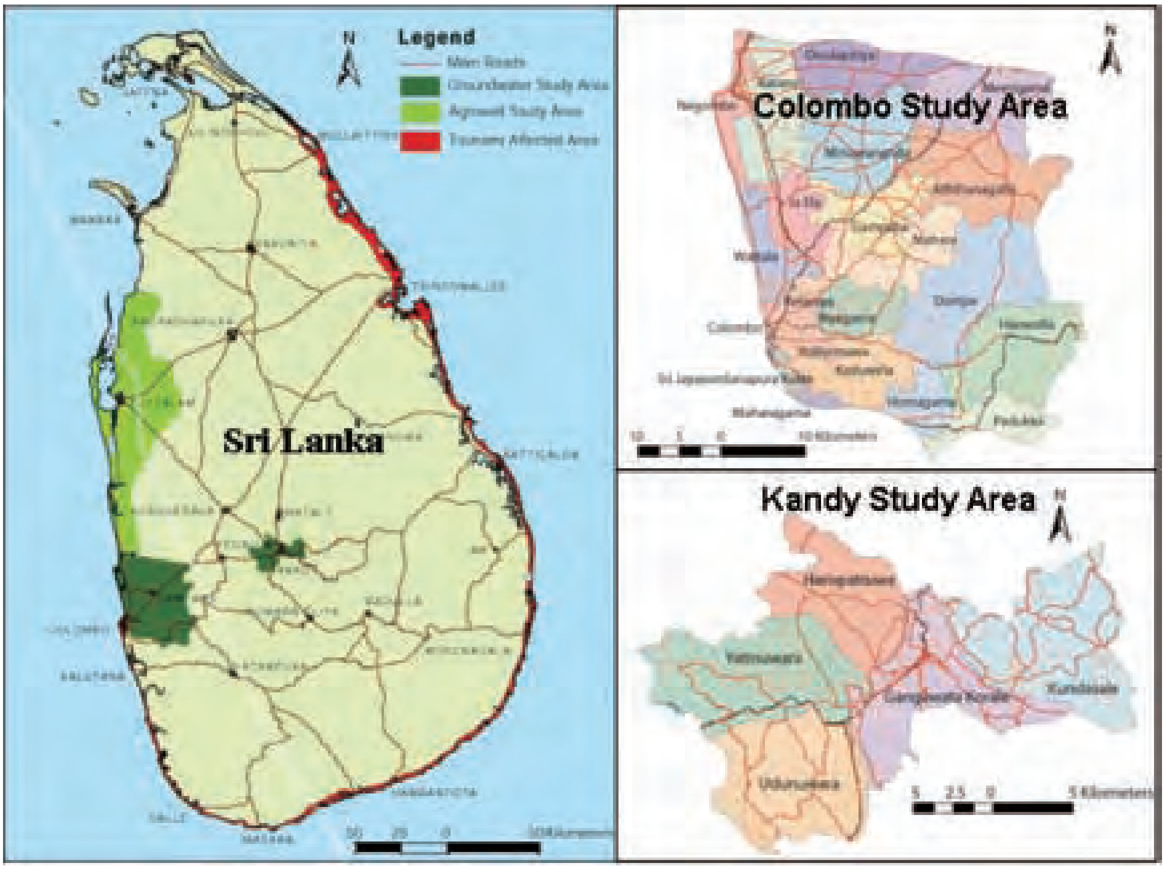


Figure 1. Case Study Areas

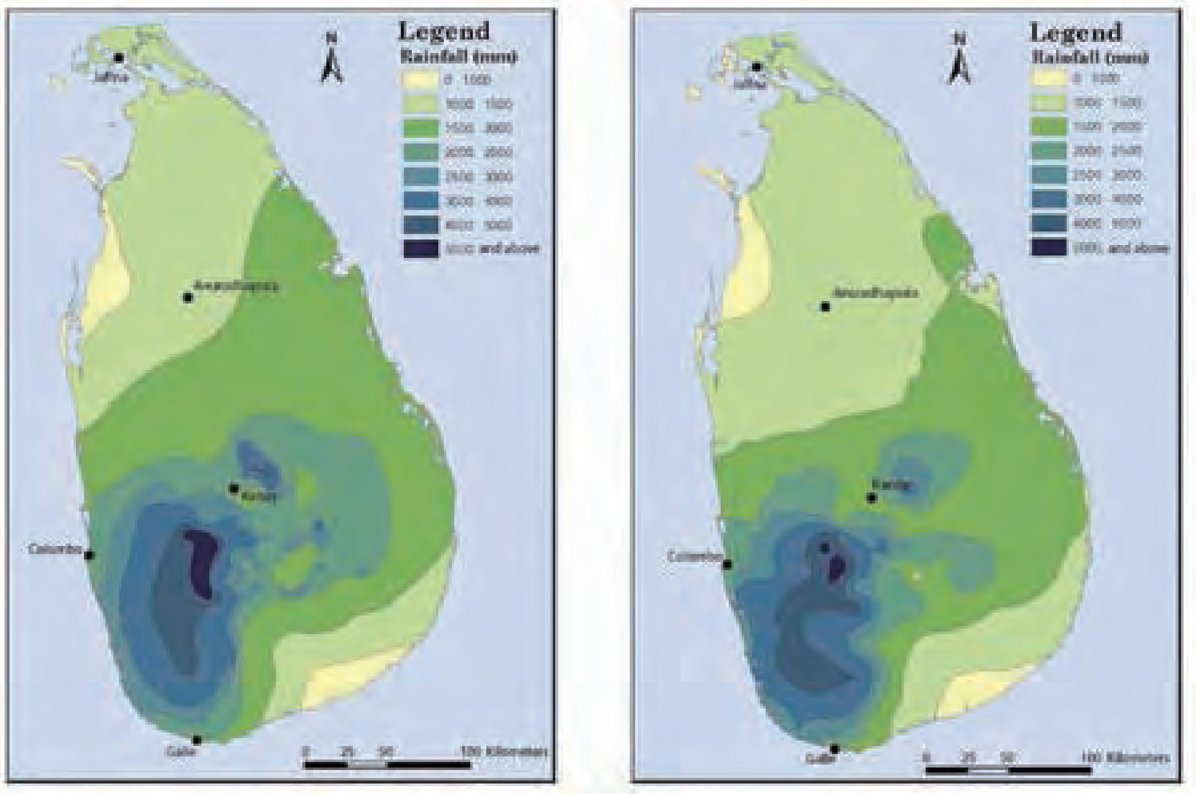
(1) Administrative Structure
Sri Lanka has nine provinces, each with its own local government. These provinces are further subdivided into a total of twenty four districts. These are again subdivided into divisional secretariat areas responsible for civil affairs, which in turn are further divided into the smallest administrative divisions, called "*Grama Niladari* Divisions," the village level. The Colombo study area (hereafter called ***Colombo***) includes twenty divisional secretariat divisions covering the **whole districts of Colombo and Gampaha,** while the Kandy study area (hereafter called ***Kandy***) is limited to only five divisional secretariat divisions covering **a portion of the Kandy district.**

1.3 Topography and Climate

(1) Topography
Sri Lanka has a central mountainous region rising up to about 2,500 m above mean sea level, with the highest elevations covered by virgin forests and grasslands. The surrounding plains, which rise to about 50 to 100 m above sea level, are largely used for agriculture and homesteads, but still have virgin scrubland where the population distribution is lower.

Colombo: Colombo is located in the coastal plains of the western region of the country. The terrain in Colombo consists of gently undulating plains with a high density of drainage paths.

Kandy: Kandy is a plateau in the central mountainous region and lies 500 to 700 m above sea level. The terrain in the Kandy City area does not contain many steep, plunging slopes except in the surrounding mountains. The topography in this plateau consists of undulating plains with hillocks formed by the drainage paths.



1911-1961 **1961-1990**

Figure 2. Rainfall Changes in Sri Lanka during the Period from 1911 to 1990
Source: Ratnayake and Hearth, 2005

(2) Climate

In terms of the amount and pattern of rainfall received, Sri Lanka can be divided into three different climatic zones. These zones are referred to as the wet zone (usually over 2,000 mm annual rainfall), the intermediate zone and the dry zone (below 1,500 mm rainfall). In general, rainfall in the island mainly occurs during the southwest and northeast monsoons and during the inter-monsoons. Both selected study areas are located in the wet zone, which receive average annual rainfall of about 1,900 mm. With the recent climatic changes happening, however, 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 decreased all over the country (figure 2) and especially around Kandy (Ratnayake and Herath 2005). Further it is revealed that the lengths of the dry periods have increased all over the country and the lengths of wet periods have decreased. These changes in rainfall have directly affected groundwater by reducing the recharge time corresponding to the lengths of wet spells and increasing exploitation with increased use during dry spells.

1.4 Geology

Colombo: The geology of Colombo is representative of the geology of the western coast of Sri Lanka and has existed for much of the Quaternary era. Bore holes drilled in central Colombo City show that this area once formed an 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 along the rivers consist mainly of alluvial deposits. The floodplains of Kelani River also provide thick alluvial profiles for unconfined aquifers, in addition to the productive overburden along tributary banks.

Kandy: The main geological feature of Kandy City and its surrounding area is a band of marble one kilometer thick. This band is 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 overburden latosolic soil that on average ranges in thickness from one to three meters. The major bedrock types available within the Kandy study area are summarized as percentages in figure 3 below. The main rock type identified is Biotite Gneiss, which cover almost half the area. Hornblende biotite gneiss, charnockitic gneiss, garnet biotite gneiss and granitic gneiss are also present in considerable percentages.

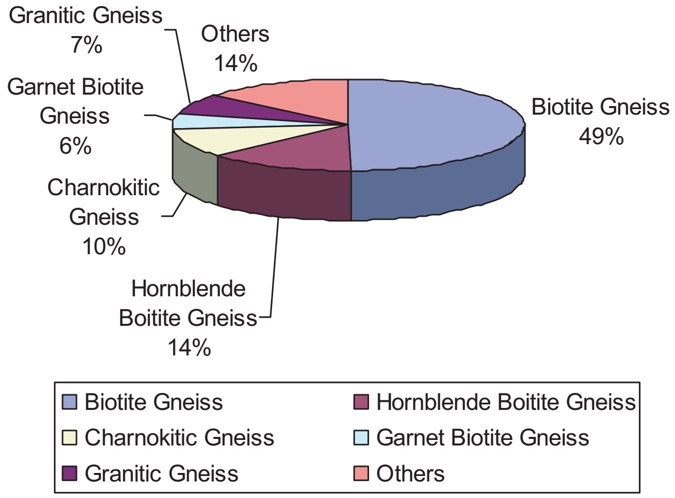


Figure 3. Geological Classification of Bed-Rock Types in Kandy Study Area

1.5 Socio Economic Conditions

Colombo: Regionally, Colombo and its suburbs accommodate the densest population in Sri Lanka. As of 2001 (last official count - Sri Lanka Data Sheet 2004 and Sri Lanka Department of Census and Statistics web page), the total population living in Colombo study area was placed at 4.3 million, with an average annual population growth rate of 1.7%

during the past 20 years. According to the Central Bank of Sri Lanka, the country's per capita GDP was at 473 USD in 1990, and had increased to 1,160 USD by 2005. Of this national GDP, the western province of which Colombo is the capital contributes almost one half (estimated at 48.1% in year 2002). Therefore Colombo, where most of the industrial, commercial and administrative activities taking place, plays a very important role with respect to the overall national economy.

Kandy: The population within the Kandy study area in 2001 was 0.81 million (Sri Lanka Data Sheet 2004 and Sri Lanka Department of Census and Statistics web page). Though Kandy is the second-largest city in the country, in comparison to Colombo its population is very small. The average population growth rate during the past 20 years in the Kandy region is estimated as 1.0%. This value is lower than the country average of 1.2%. As of 2002, the contribution to the national GDP from the Kandy district was only 9.4% (Central Bank of Sri Lanka web page).

1.6 Land Use

Colombo: The total land extent of the Colombo case study area is 1,575.6 km^2. Land use changes during the recent past in Colombo are tabulated in table 1 below. According to the data, the main land use change observed in the Colombo study area is the rapid increase in built-up land, which grew by 933% over the eleven years from 1987 to 1998. This built-up area replaced domestic gardens, water bodies and marshes (a typical domestic garden in Sri Lanka mainly consists of mixed vegetation that surrounds the house). There is also a significant decline in the extent of domestic gardens observed, mainly due to migration to commercial crops.

Kandy: The selected study area in Kandy is only 322 km^2. Compared to Colombo, major land use changes observed in Kandy were in forest cover, built-up area and domestic gardens. Forest cover increased over 100% during the eight years from 1988 to 1996. This increase replaces the domestic gardens and agricultural land. The change in built-up areas was only 48.2%.

However, in both these study areas, a significant reduction was observed with respect to the cropping intensity of paddies, which cover nearly 20% of the total land area. This change is not clearly reflected in the land use maps. Paddy cultivation in the last decade has dropped compared to the late 1970s, and this may substantially restrict the amount of irrigation water in the paddy fields, thereby reducing the sub-surface flow and recharge, which in turn influence the groundwater resources in the area.

Table 1. Land-Use Changes in Colombo

Land-Use Type	1987 (km^2)	1998 (km^2)	% change
Agricultural land	572.5	799.1	39.6
Built-up land	12.7	131.2	933.1
Forests	36.4	30.5	-16.2
Domestic gardens	848.1	560.9	-33.9
Water bodies	53	21.5	-59.4
Mangroves and marshes	52.9	32.4	-38.8

Source: Land use maps, Survey Department of Sri Lanka

Table 2. Land-Use Changes in Kandy

Land-Use Type	1988 (km^2)	1996 (km^2)	% change
Agricultural land	109.1	104.4	-4.3
Built-up land	5.6	8.3	48.2
Forests	22.1	46.5	110.4
Domestic gardens	175.6	149.9	-14.6
Water bodies	9.6	10.4	8.3
Mangroves and marshes	-	-	-

Source: Land use maps, Survey Department of Sri Lanka

2. State of Water Resources

According to the "Earth Trends" country profile on Sri Lanka (2003), the total renewable water resources available in the freshwater ecosystems of Sri Lanka are estimated at 49 km^3 as surface water, 8 km^3 as groundwater, and a further 7 km^3 as overlapping water. The wet zone, which receives over 1,900 mm rainfall annually on average, generates 49% of the total runoff for the entire country. Because of this runoff, the overburden in wet zone is kept moist, which allows considerable subsurface flow through macro pores. These subsurface flows are tapped using shallow wells throughout the study areas, providing water for the majority of the population.

In terms of river basins, the major part of the Colombo study area is located in the lower catchment of the Kelani River, while the entire Kandy study area is located in the middle catchment of the Mahaweli River basin. Therefore both these areas are rich in surface water resources.

2.1 Water Resource

(1) Groundwater Resource

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 4 shows the distribution of these aquifers within the country (Panabokke and Perera 2005). In addition to these main aquifers, a large number of small groundwater pockets can be found throughout the country. These aquifers occur either in isolated patches of soil cover over the bedrock or in the fracture and weathered zones of the underlying metamorphic bedrock.

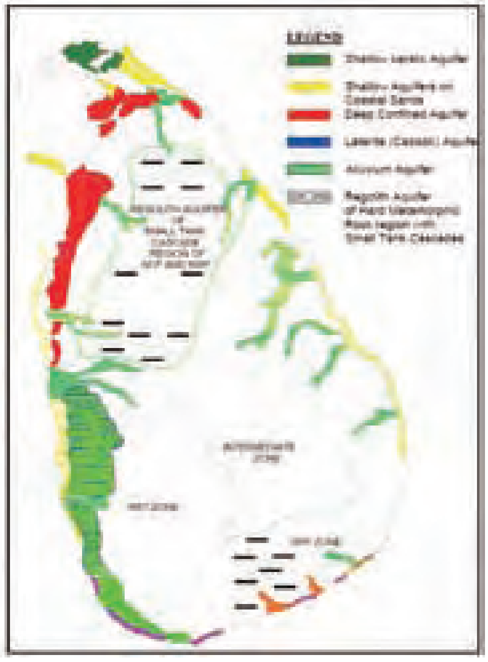


Figure 4. Distribution of the Major Aquifer Types in Sri Lanka

Source: Modified from Panabokke and Perera 2005

a. Groundwater Hydrogeology of study locations

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 good conditions for deep aquifers. The alluvial sand/gravel aquifers in the basin are recharged by rainfall and 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. This groundwater exits both as small pockets of underground reservoirs and as fissure groundwater. The yields of these aquifers are not very well known and are limited as they recharge very slowly. In addition, there exists high-yielding groundwater resources along the alluvial flood plains of Mahaweli River that are mostly recharged by the river water.

(2) Surface water resources

Since both study areas are located in the wet zone, they are blessed with plenty of rainfall and therefore surface water. However, when the total surface water availability of the areas is considered, depending on the location of demand centres and the location of water resources with respect to the demand centres, it is difficult to find suitable water resources for some demand centres in the study regions. Also, even though the available water resource is good, when one considers the total aggregate water availability, the variations over space and time from the historical perspective demand a proper management strategy.

Colombo: Kelani River, with the third largest watershed in the country, is the main surface water source for the Colombo region. Therefore, the Kelani River water is playing an important role with respect to the Island's overall economy, since it drains the most fertile lands in the wet zone and intercepts the most populated and economically important administrative district of Colombo the capital of Sri Lanka. In the Colombo study area, the principal use of water from the Kelani River is for water supply, including to the Greater Colombo area at Ambatale. The Kelani River is 144 km long and drains an area of 2,292 km^2 originating at levels above 1,500 m on the steep slopes of the western rim of the central highlands. In their descent the main river and its numerous tributaries travel through deep, structurally controlled valleys, generally oriented in many directions at higher and lower elevations. The main river eventually empties into the Indian Ocean on the west coast of Sri Lanka just few kilometers north of Colombo. The Kelani catchment receives an average annual precipitation of 3,718 mm generating a surface runoff volume of about 8,600 million m^3 of which nearly 65% discharges into the Indian Ocean. In addition to the Kelani River, Attanagalu Oya, a non-perennial stream, also flows through the study area but has limited significance with respect to supplying water to the Colombo study area.

Figure 5. River Basins in Sri Lanka and within Study Areas
Source: Sri Lanka National Water Development Report 2006

Kandy: In addition to rainfall runoff, the only other major surface water source available within the Kandy study area is the Mahaweli River. The Mahaweli River is the longest river in Sri Lanka; originating in the highlands and running in the northeasterly direction through Kandy to Trincomalee to the ocean and draining an area of around 10,300 km^2, nearly 16% of the total land area of the island. As this perennial river flows through the study area, a considerable amount of surface water is available in the study area throughout the year. Furthermore, the tributaries Maha Oya, Pinga Oya, and the Nanu Oya of the Mahaweli River have the potential to supply substantial amounts of water during the rainy seasons to the Kandy study area. However, as the major portion of the Mahaweli River flow through Kandy is regulated at Polgolla and diverted for hydropower and for agriculture towards large irrigation networks in dry zones of Sri Lanka, satisfying these demands together with the Kandy water requirements in the future is of some concern.

2.2 Water Usage Practices

(1) Groundwater

The demand for water in Sri Lanka is steadily increasing, particularly for urban/rural water supplies, irrigated agriculture and in 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 the urban population was supplied with a piped supply compared to 11.4% in rural areas, while the urban and rural populations using underground well-water were estimated at 22.4% and 71.8% respectively (that urban and rural populations in 1999 were 5.86 and 13.05 millions respectively). Also, in recent times use of groundwater is on an increasing trend because of high piped water tariffs and restricted hours for water supply. These two issues have forced the industrial and commercial users and some individual domestic users around the country who are already supplied with piped water to 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 free, safe, of good quality, and able to be autonomously managed. Presently, there are around 30,000 deep groundwater wells throughout the country registered with the Water Resources Board (WRB). However, this figure does not take into account all groundwater wells in Sri Lanka because wells constructed/developed by the National Water Supply and the Drainage Board (NWS&DB), private drilling organizations and overseas projects have not been included in this registration.

With respect to piped water supply, presently there are 93 urban and rural water supply schemes operating across the country that rely purely on groundwater, accounting for 31% of the total supply. The total amount of annual groundwater abstraction from these 93 schemes is estimated to exceed 16 million m^3. A summary of the groundwater use within the two study areas is tabulated in table 3.

Table 3. Groundwater Use in the Study Areas

	Colombo		Kandy
	Colombo district	Gampaha districts	
Ground water for piped supply (m^3/day)	0	5,859	8,567
Groundwater use (individual) (m^3/day)	78,000	156,000	41,000
Population relying on groundwater (%)	34.8	75.4	52.0*
Registered deep borehole well number	342	890	1,754*

*Note; * district values*

Colombo: At present there are no water supply schemes relying on groundwater in the Colombo district. However, the amount of groundwater used in piped water supply schemes in the Gampaha district in the Colombo study area is 5,859 m^3/day (10% of total supply in Gampaha - Panabokke and Perera 2005). As shown in table 3, the total numbers of registered deep groundwater abstraction wells in the Colombo and Gampaha districts are only 342 and 890 respectively making a total of 1,232. In comparison to other cities in the Asian region, this number is very small, but the population relying on shallow groundwater within these two districts is estimated as 34.8% and 75.4% respectively. These high percentages are mainly due to poor pipe water coverage. Individual domestic use in the Colombo study area is estimated to be consuming approximately 85 million cubic meters of groundwater annually. Here, as there is no system of recording the groundwater use, only estimations can be made. Further, it should be noted that this estimation excludes groundwater use by houses that already have a pipe water connection and use groundwater as a supplementary source. Since the percentage of domestic consumers with a piped water supply and using groundwater as a supplementary source, especially in peri-urban areas, is believed to be high and also increasing, the above estimations may be lower than the actual groundwater use.

Kandy: The amount of groundwater use by the piped water supply schemes within the Kandy region is estimated at 8,567 m^3/day (around 12% of the total piped water supply). As shown in table 3, the total numbers of recorded deep groundwater abstraction wells in the Kandy district is 1,754, a much higher value than in the Colombo region. Further, the percentage of the population relying on groundwater in the district is almost 52% and individual domestic groundwater consumers are estimated to be using approximately 15 million m^3 annually.

(2) Surface water

Colombo: In total there are 10 major surface water supply schemes operating within the Colombo study area using surface water. The annual supply from these schemes in 2001 is estimated as 286 million m^3. Except for a small volume taken from the Labugama and Kalatuwawa tanks, all remaining surface water requirements are extracted from the Kelani River. However, as the Colombo water supply intake at Ambatale is only 16 km upstream from the ocean confluence, less than 15 m above mean sea level, it is estimated that unless a salinity barrier across the river is constructed, a minimum of a 33 m^3/s flow is necessary at Ambatale to prevent saltwater intrusion into water intake (Kelani Ganga Basin – 1999). However, our study analyzing the recent salinity problems at Ambatale estimates that a minimum flow of 30 m^3/s is required for salinity control. Additionally there are several other schemes upstream of Colombo that rely on Kelani water for their water supplies.

A summary of potable water use in the 2000-2001 period is given in table 4 below. As given in the table, the non-revenue water (NRW) component is nearly 35-40 % of the total water supply, making it a significant component in both the study areas. These percentages are very high compared to NRW values of the other countries in the region.

Table 4. Domestic and Industrial Water Use within the study areas

	Surface water (m^3/day)		Groundwater (m^3/day)			NRW (m^3/day)
	Domestic	Industrial	Deep	Shallow		
			Domestic	Industrial	Domestic	
Colombo (2001)	380,248	158,445	11,151	6,970	234,000	243,956
Kandy (2000)	36,679	5,972	5,546	804	41,000	22,928

Kandy: In Kandy there are only 7 major surface water supply schemes operating within the study area. These schemes distribute over 25 million m^3/year of water (2001). This entire surface water demand is extracted either from the Mahaweli main river or from its tributaries. Additionally in November 2006, the pipe water distribution to Kandy was further increased by another 19 million m^3/year. This was mainly to upgrade the existing supply in the region and to replace some of the existing problem-prone groundwater supply schemes. With this addition, the current surface water extraction from Mahaweli has increased to 44 million m^3/year. Further, even though the total irrigation requirement in the Kandy district is only 1.6m^3/s (but within the study area is only 0.4 m^3/s), a large amount of surface water from Mahaweli River is diverted at Polgolla to northern parts of Sri Lanka for irrigation purposes. The minimum diversion requirement at Polgolla is estimated at 14 m^3/s in February and March, and the maximum at 36 m^3/s in June. Also, in addition to these requirements, a further 4.2 m^3/s flow is required as environmental flow to satisfy the downstream requirements below the Kandy study area.

2.3 Resource Availability

(1) Groundwater

Colombo: Although there have not been many studies done, in a study under the "Kelani Ganga Basin Study – 1999," the sustainable aquifer yields within different hydrogeological settings of Colombo study area, especially in the Kelani basin have been forecast by the Danish Hydraulic Institute. The estimated yields during this study are shown in table 3 below.

Kandy: In contrast to Colombo, there have been few attempts in Kandy to estimate the groundwater potential in the region. During the 1980-1984 period, one such study was done with foreign assistance through aerial photos and *Landsat*-maps, geological and geophysical studies, topographical map studies, investigational drilling, pump testing, etc. Furthermore, in 1988 another similar investigation has been done in Kandy to determine the suitability of geophysical investigation methods for assessing the aquifer yields in the region. However, the conclusion of both these studies was that none of the methods used were suitable for local conditions in Kandy.

Since there were no reliable estimations for aquifer yields available, an attempt was made during this study to find out the aquifer behavior in three of the divisional secretariat (DS) areas of the Kandy study area, the Harispattuwa, Kundasale and Udunuwara, with the help of available information. In this analysis the borehole logs were studied for construction yield with the yield variation by rock type on which the well was constructed. The obtained comparative results are shown in Table 4 and Table 5 for the borehole yields and borehole success rates respectively. According to this comparison, it was observed that most of the analyzed wells had yields of less than 100 l/min; in fact 81% were less than 100 l/min, 16% between 100-1000 l/min, and only 3% greater than 1000 l/min.

Table 5. Estimations for Annual Sustainable Yields

Aquifer Type	Estimated yields ($\times 10^6$ m^3/km^2/year)
Gravel/Pebble	0.91
Vesicular laterite	0.73
Karstic Crystalline Limestone	0.66
Quartzites	0.73
Fractured bedrock	0.55
Clayish sands	0.37

Source: Kelani Ganga Basin Study – 1999

Table 6. Borehole Yield

Yield (l/min)	Udunuwara (%)	Kundasale (%)	Harispattuwa (%)
0-100	80	83.33	46.67
100-1000	18.3	13.6	33.33
>1000	1.7	2.7	20

Source: National Water Supply and Drainage Board, Kandy

Table 7. Borehole Yield and Success with Rock Type

Rock type	No.	Yield (m^3/day)	Success (%)
Biotite Gneiss	135	248	52
Hornblende Biotite Gneiss	37	482	76
Charnockitic Gneiss	28	716	50
Garnet Biotite Gneiss	15	69	53
Granitic Gneiss	19	206	42
Biotite Gneiss with Calcite	4	156	25
Calcite Gneiss	4	122	50
Marble	8	747	37
Charnockite	3	29	33
Charnockitic Biotite Gneiss	5	148	80
Quartz Feldspathic Gneiss	5	-	00

Further the results in table 7 shows that failure rates in construction in Udunuwara and Kundasale DS divisions are over 50%, but comparatively less in Harispattuwa DS division. As shown in figure 3 previously, the main bedrock type in the Kandy study area is biotite gneiss (49%). However, hornblende biotite gneiss, charnockitic gneiss, garnet biotite gneiss and granitic gneiss are present in reasonable percentages as well. Comparing the borehole efficiency (high efficiency means both high yield and high success rates) with bedrock geology, boreholes in hornblende biotite gneiss and in charnockitic biotite gneiss formations give good groundwater. Conversely, poor efficiency is observed in areas with biotite gneiss, charnockitic gneiss, garnet biotite gneiss, granitic gneiss, charnnockite, and marble rock formations. These formations cover over 73% of the total study area in Kandy. Therefore, the ground water potential in the hard rock formations around the Kandy region is highly questionable. Since there is no continuous monitoring data available, substantiating this claim with actual data was not possible.

(2) Surface Water

Colombo: The Kelani River is the major surface water source used in the Colombo. As discussed earlier, the existing water intake to Colombo is located at Ambatale, only 16 km upstream of the ocean outfall. Therefore the Kelani stream flow was investigated just upstream of Ambatale at Hanwella, analyzing the river discharges from 1973 to 2004. The finding from this analysis is summarized in table 8 below. According to this analysis, a minimum average river discharge of 68 million m^3 was observed in February and a maximum of 373 million m^3 in the month of June at Hanwella.

Table 8. Available Surface Water in Study Areas

Monthly Average Flow (million m^3)	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mahaweli at Peradeniya	89	47	47	71	129	224	299	224	187	217	234	158
Kelani at Hanwella	94	68	98	162	286	373	275	211	233	345	297	156

Source: Deparment of Irrigation, Sri Lanka

Kandy: The Mahaweli River is the major surface water source for the Kandy study area. Although there are several tributary streams flowing into the main river from Peradeniya to Polgolla, the cumulative discharge from those streams is substantially lower (less than five percent) than the main river. Similar to the Kelani River, an analysis for Mahaweli River flow discharges at Peradeniya Gauging Station between 1964 and 1993 show the highest average monthly discharge of 299 million m^3 in July and lowest of 47 million m^3 in February (table 8).

(3) Rainfall

Colombo: Though a fair amount of rainfall is on record for both the study areas, their seasonal distribution is closely associated with the monsoon pattern. According to historical data, the 40 year average annual rainfall in Colombo is 2,376 mm. Further, the maximum and minimum monthly average rainfall observed in Colombo during this period was 360 mm in May and 78 mm in February respectively.

Kandy: Similarly the 60 year annual average rainfall in the Kandy study area is 1,841 mm. In addition, the maximum and minimum monthly average rainfall observed in Kandy during this period were 278 mm in November and 68 mm in April respectively. Further, a closer look at the rainfall variations in Kandy shows that the annual rainfalls are following a decreasing trend, as shown in figure 6. This trend raises many uncertainties over the future of surface water.

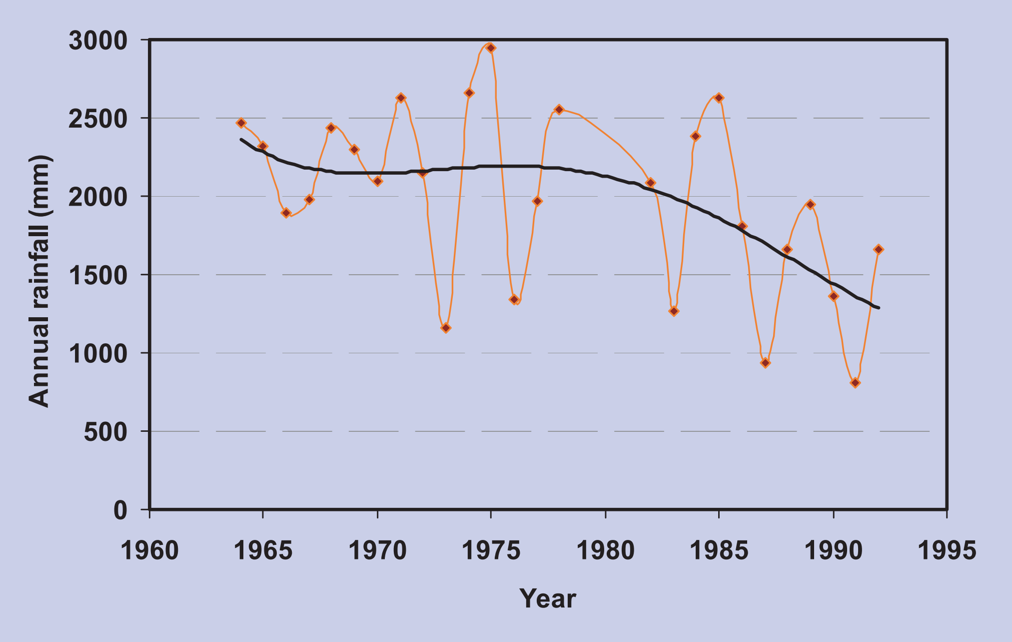


Figure 6. Annual Rainfall Variations in the Kandy Region
Source: Metereological Department of Sri Lanka

Groundwater user trends in 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 abstractions, 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. 2001). This rapid, haphazard expansion of agro-wells without appropriate assessment of factors such as the hydrogeological environment is expected to create many problems. As farmers are used to abstracting groundwater at rates typically ranging between 27 m^3/hour and 45 m^3/hour (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.

2.4 Piped Water Coverage

(1) Present Supply Coverage

The present (2005) safe drinking water coverage of the country is estimated at 69%. The Government of Sri Lanka expects to increase its investment in water supply to achieve a safe water coverage target of 87% by the year 2015 and nearly 100% coverage in 2025. A number of new projects have been launched with local and foreign funding to achieve this target. Total pipe water production in Sri Lanka in the year 2005 was estimated as 383 million m^3. In Sri Lanka, access to safe drinking water is interpreted as having a source or water supply satisfying the Sri Lankan standards for drinking water, which are more stringent than the WHO standards. Therefore "safe drinking water" in this section implies that the water is within the minimum required standards for drinking.Poor monitoring, however, especially in community wells and individual groundwater extractions, raises many doubts on the actual safety of this water.

Colombo: According to National Water Supply and Drainage Board (NWS&DB) information, figure 7 below shows the percentage of people using different water sources for their drinking water needs within the two study areas. The Sri Lankan Government established NWS&DB in 1974 for providing safe drinking water to the population. According to these data, 62% of the population in Colombo study area is served with piped water and of the rest, 36% use protected groundwater and the other 4% unsafe water sources, such as streams and unprotected wells.

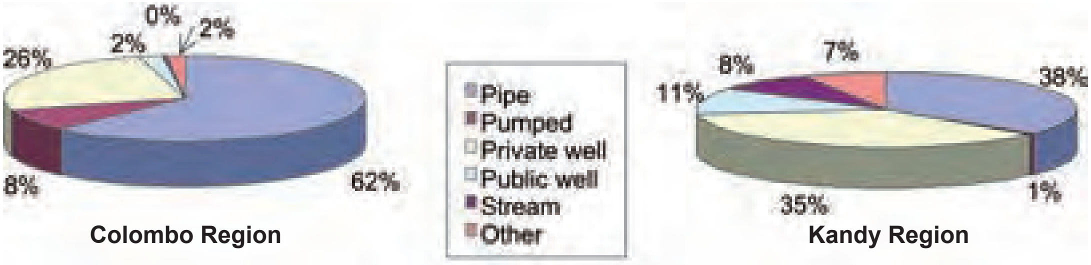


Figure 7. Sources for Drinking Water in the Study Areas in the Year 2000 (NWS&DB data)
Source: Statistical Abstract 2005, Department of Census, Sri Lanka

Kandy: As shown in Figure 7, only 38% of the population in the Kandy study area is served with piped water, and of the rest 47% use groundwater and 15% others unsafe water sources, such as streams and unprotected wells.

(2) Future Water Supply Demands

Colombo: At present in Colombo, the surface water is mainly used for drinking/recreational purposes. Using the population growth trends in the past, industrialization trends and the NWS&DB 1991 Master-Plan documents, future water demand for various sectors within the Colombo study area was estimated. The obtained water demands are shown in Table 8a below. According to this estimate, even in the year 2020, the major water requirement will be for satisfying the domestic demand. The forecasted industrial demand in 2020 will only be around 40% of the 2020 domestic demand.

Table 9. Water Supply Requirements in Colombo according to Sector and Source

Usage (m^3/day)	2001		2010		2020	
	Surface	Ground	Surface	Ground	Surface	Ground
Domestic supply	380,248	105,621	441,971	115,328	506,325	118,684
Industrial supply	158,445	6,970	181,508	7,129	198,898	9,465
Other	33,280	976	46,098	1,810	58,913	2,803
NRW	243,956		206,138		200,051	

Kandy: Surface water in the Kandy study area too is mainly used for a) drinking/recreational purposes, b) diversion/transfer requirement at Polgolla for hydropower generation and irrigation and c) to maintain minimum flow requirement in the downstream. With the population in the Kandy study area expected to reach 1.04 million by the year 2025, the

Table 10. Water Supply Requirement in Kandy According to Sectors and Sources

Usage (m^3/d)	2000		2015		2025	
	Surface	Ground	Surface	Ground	Surface	Ground
Domestic supply	36,679	31,300	61,029	98,415	86,336	107,207
Industrial supply	5,972	804	15,157	1,684	16,690	1,451
NRW	22,928		28,068		18,141	

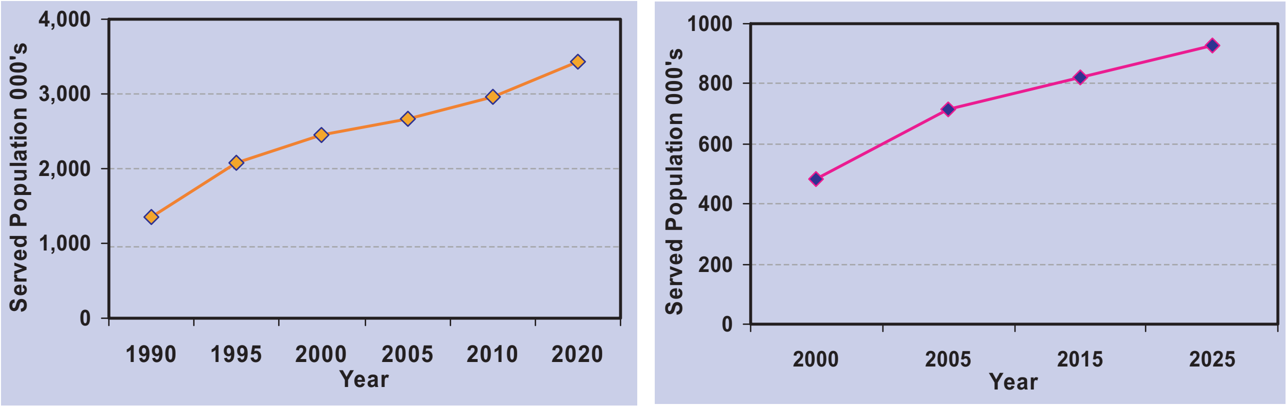
estimated future potable water demand in Kandy is tabulated in table 10 below. In addition to these requirements, the Kandy Water Supply Master Plan document proposes diverting surface water from Mahaweli River to the adjoining Kurunegala District for drinking purposes.

(3) Future Water Supply Developments

Colombo: Master Plan documents of the NWS&DB details the proposed future pipe water supply coverage plans within the two study areas. The planned supply coverage by year 2025 proposed in the Colombo report is shown in Figure 8. According to the proposals, piped water coverage will increase from the present 2.67 million people to 3.47 million people by 2020 in this study area.

Kandy: According to figure 8, which was based on the Kandy water supply Master Plan Document of 2001, pipe water coverage within the Kandy study area will increase from the present 0.31 million people to 0.395 million people by the year 2025.

In addition, the safe drinking water coverage augmentations planned during the next 20 years within the Kandy district is given in table 11. According to these data, the highest coverage increase of 19% is expected from pipe water augmentations. By the year 2025, 10 new piped water schemes are foreseen to be constructed. Already two large surface water treatment schemes are under construction there: the North of Kandy Town Project to cover the central and northern parts of the region, and the South of Kandy Town Project to cover the western and southern parts of the regions. However the expansion in groundwater use forecasted for the future is small as the expected increases in tube wells and protected dug wells supply is estimated only at 1.0%-3.5% respectively.



Colombo

Kandy

Figure 8. Future Water Supply Coverage in Colombo and Kandy

Source: National Water Supply and Drainage Board, Water Supply Master Plans for Colombo 1991 and Kandy 2001

Table 11. Mode of Safe Drinking Water Coverage in Urban and Rural Areas of Kandy District

Mode of supply	Drinking Water Coverage(%)			
	2000	2005	2015	2025
Pipe borne	38.0	54.0	55.8	57.0
Tube Well	15.0	15.5	15.8	16.0
Protected Dug Well	15.5	17.0	18.0	19.0
Other	0.5	1.0	1.5	2.0
Total	**69.0**	**87.5**	**91.0**	**94.0**

Source: National Water Supply and Drainage Board, Water Supply Master Plan for Kandy 2001

3. Issues of Groundwater Management

Over the past 30 to 50 years, there have been three main state agencies involved in groundwater development in Sri Lanka. They are the Water Resources Board (WRB), National Water Supply and Drainage Board (NWS&DB) and the Agriculture Development Authority (ADA). In addition, a few private drilling companies and donor-funded projects have also been engaged in the investigation and development of this 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 mostly limited to deep wells. In most cases, the recorded information is restricted to the drill log, the initial water levels, and the initial water quality. There is no information available on wells constructed by private drilling companies. Because of this, there is no continuous groundwater-related monitoring data available, and hence there is no means of controlling the adverse impacts from the developments taking place in recharge areas.

The history of well construction in Sri Lanka itself is indicative of the success rate. The 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 l/min and hand-operated tube wells that yield less than 4 l/min 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 a smaller reduction in yield and continue at a lesser yield. Usually a well will achieve a steady state after about five to eight years. If a well fails to continue to function at the rates mentioned above, it will be classified as a failed well. Usually the average success rate achieved at this stage for the whole country is about 65%. This rate is slightly higher for dry-zone wells maintained by the community, which stay at about 70%. The lower success rate achieved in wells maintained by the local governments is attributed to poor maintenance and over-abstraction. Addition to this data, our investigations showed that in the Kandy area, the success rate was only around 50%, much lower than the national average, even as early as at the drilling stage for deep boreholes. Further, the yield at drilling in majority of these borehole wells in Kandy is below 144 m^3/day, thus making them suitable only for small-scale water supply systems.

The general opinion among many officials involved in groundwater development in Sri Lanka is that the exact reasons for most of the borehole failures are not commonly known because one would require a borehole camera to investigate, and this facility is not available in the country. Further, though there are various other opinions concerning the country' s groundwater issues, lack of data and the wide range of abstraction across many different aquifer environments make the problem analysis very complicated. Hence in this section, the quantity and quality-related issues experienced in the study areas are discussed in a more generalized form.

3.1 Quantity-related Issues

Colombo: Most of the quantity problems experienced in this study area occur in the coastal aquifers, vesicular laterite aquifers or in semi-confined rock aquifers. In addition, there is a significant amount of groundwater abstraction using very productive alluvial aquifers along the river and tributary banks. In the coastal regions of Colombo, over-exploitation is seen as a major threat to the sustainable use of its coastal sand aquifers (e.g., water supply system in Ragama). These thin, freshwater lens aquifers that float on saline water are often contaminated with saline water due to excessive abstraction, especially during prolonged droughts. In regions of vesicular laterite aquifers, some are highly productive, and therefore they are commonly used for medium-scale piped water supply schemes. The excessive abstraction that mostly occurs in these laterites located away from the flood plain results in the lowering of the water table (industrial zone in Ekala). When these aquifers are used excessively, the aquifers themselves are subjected to localized groundwater table depletions affecting the groundwater wells in the surrounding areas. These coastal aquifers and laterite aquifers are only available in the Colombo study area and not in the Kandy study area.

The other major groundwater extractions are coming from semi-confined bedrock aquifers. These semi-confined rock aquifers are used in high-volume requirements such as industrial activities, and by water-supply schemes. According to the NWS&DB, most of these deep, hard rock abstraction wells have experienced either a rapid lowering of their water levels or decreased yields or both. Since there is no continuous monitoring being done, the only information available on these boreholes is the initial drill log, initial water quality, and test pump results. Hence the actual causes for these failures are largely unknown. In such failures, the usual practice adopted by the authorities is to drill another new borehole in the vicinity, and in some cases, only a few meters away from the existing well, to replace the problematic borehole. This has been possible since the groundwater resources in hard rock formations are highly variable even within a very close proximity. Many officials involved in groundwater abstraction suggest that a poor understanding of the resources and poor preliminary investigations, inadequate monitoring, and poor maintenance are the main causes for these failures.

Kandy: Most of the quantity problems experienced in this study area occur in the semi-confined bedrock aquifers. In this region too, the current problems associated with these rock aquifers are very much localized. In addition, there is a significant amount of groundwater abstraction using very productive alluvial aquifers along the river and tributary banks. Personal communication shows that there are a number of groundwater schemes in the Kandy study area such as the Kondadeniya scheme, Gohagoda scheme, Kulugammana scheme, Hedeniya scheme, Yatihalagala scheme, etc., that have been abandoned due to water depletions. Furthermore, a number of schemes such as Ampitiya, Galhinna, Bokkawala, Ankumbura, Akurana-Welekade, Alawathugoda and Rajapihilla schemes are suffering from lower yields. All of these schemes were initiated in the early 1980s and, at present, almost all schemes operating using hard rock deep aquifers are failures and the water supply is restricted to few hours a day on a few days per week. In the Kandy region, unlike in Colombo, the success of drilling new bores in the vicinity as a solution had only limited success, as, in most cases, water had to be taken from places far away from the existing intake boreholes, making the supply very expensive. Even these new borehole locations also had run into many problems as they were in hard rock formations. Consequently, a massive surface water facility to replace the groundwater schemes was constructed in November 2006, and now some of the schemes closer to the Mahaweli River—Kondadeniya, Kulugammana, Yatihalagala, Gohagoda, Rajapihilla—that previously operated using groundwater have been replaced by the water from this new surface water scheme.

Using the limited data available, monthly minimum and maximum extractions from one of the borehole stations in Harispattuwa DS division at Owissa was analyzed. The obtained plot is shown in figure 9. According to the available data, the maximum pumping rate is around 500 to 600 m^3/day, which is also using two borehole wells. At the test pumping, the recommended yield for this borehole field was in excess of 1,500 m^3/day.

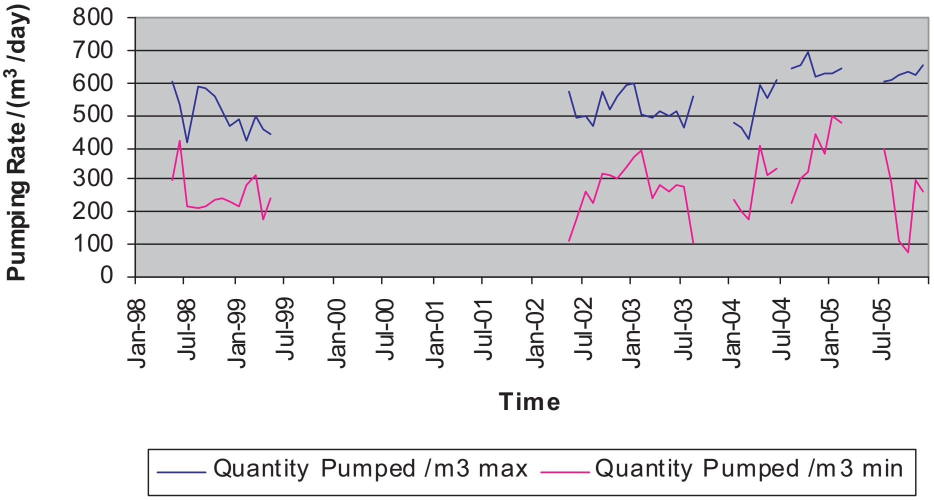


Figure 9. Groundwater Pumping Rates in Owissa (Kandy study area)
Source: National Water Supply and Drainage Board, Kandy

Considering all the above information, the most common failure modes in the boreholes constructed on hard rock formations can be listed as:

i. Clogging the fracture zone/path of borehole wells, thus failing to recover even after flushing. Past experience in Sri Lanka shows that not all wells recovered even after repeated flushing.
ii. As the storage in a hard rock aquifer is limited, this type of aquifer will exhibit higher yield at construction but gradually deplete due to over-exploitation. It is very difficult to determine a so-called “safe yield.” In a situation such as a test pumping, the storage can exhibit a higher yield than the actual yield.
iii. Slow recharging potential in hard-rock/crevice aquifers.
iv. In some aquifers, siphon action within the fracture zone can bring substantial water volumes, and its failure caused by excessive pumping can drop the water levels considerably making the yield drop drastically.
v. Lack of information to take timely and adequate measures.

3.2 Quality-related Issues

Colombo: Though legal provisions are available with the Water Resources Board of Sri Lanka (WRB) to control groundwater pollution, there is no mechanism available with the WRB to monitor the groundwater quality continuously. Random or quality data is limited to the initial measurements done during developing the resource and that quality monitoring is not mandatory either. However, the NWS&DB monitor groundwater quality in water supply schemes under them. Based on the random quality measurements available, table 12 below summarizes the general groundwater quality in the Colombo study area. The available quality data does not raise many concerns in deep groundwater, except for high iron content in some locations. However, since there are many small- and medium-scale industries specially located in the suburban parts of Colombo that have no proper wastewater disposal systems, many shallow water contamination problem complaints arise there. In one such case, an investigation for heavy metal concentrations in shallow groundwater was done by Gunawardhana et al. in 2002. This study found that many in southern parts of Colombo have abandoned their drinking wells mainly due to problems of odor and taste. It also reveled that, as expected, most of the industries in this area tend to discharge untreated or partially treated effluent into nearby drains, polluting the groundwater. The heavy metal concentrations measured during this study shows that the area groundwater is high in Fe, Mn, Ag, Ni and Al concentrations. The summarized average and maximum concentration of heavy metals in well waters detected during this study is tabulated in table 13 below.

Table 12. Groundwater Quality in Colombo

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

Table 13. Concentrations of Heavy Metals in the Groundwater in Southern 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

Source: Gunawardhana et al. in 2002

Kandy: Similar to Colombo area, there is almost no continuous groundwater quality monitoring done in Kandy either. But, as there are many borehole wells constructed in the suburban areas in Kandy, based on the quality measurements taken in these locations during construction, table 14 below summarizes the groundwater quality in the suburban areas. According this data, hardness, iron and nitrite are of concern in some locations in southern, western and eastern regions. Hardness as high as 1,125 mg/l is observed. Further, total iron concentration of 18 mg/l, nitrites 128 mg/l and sulphates of 500 mg/l is observed. A notable point with these results is that the groundwater quality in the northern areas is found to be very good.

In addition to the above water quality measurements, there have been a few quality measurements taken for shallow groundwater wells over the last few years. Although they have not been tested at regular intervals or at regular locations, some trends can be observed with these measurements. Generally, most of these quality tests are made on request and for some of the boreholes 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 14. Groundwater Quality in Kandy (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	2,190	4.6 - 7.9	15.2	500	1,096	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	1,125	48	4.4	-	-

Source: National Water Supply and Drainage Board, Kandy

3.3 Future Groundwater User Trends in Colombo Study Area

The piped water tariff in Sri Lanka has increased over tenfold during the past twenty year period. Presently the cost of a unit of water (1 m^3) ranges from a low of 0.011 USD for the first 10 units to a high of 0.7 USD a unit for units consumed above 40. As such tariff increases surely reduce the piped water consumption, consumers may tend to use more groundwater, which is freely available. Therefore, to ascertain consumers' perception a questionnaire survey was conducted in the peri-urban areas north of Colombo with the primary objective of studying the effect of the recent tariff increase on water consumption and on groundwater use. In addition, water use pattern, opinion on groundwater, sanitary conditions, and groundwater use were also questioned. In total over 375 samples were collected.

The obtained results show that a majority of consumers with pipe connections trust the pipe-borne water, especially for drinking and in-house use. However, a substantial percentage of respondents are using groundwater as an alternative source. In addition to this, many consumers' feeling is that groundwater is safer than the piped water supply. Further to this, an effort was made to ascertain the future trends in groundwater use by allocating different weights (both negative and positive weights with average 0) for key questions asked in the questionnaire based on their importance. According to this analysis, a net value of +1505 was obtained. Therefore it can be predicted that there will be an increasing trend in groundwater use in the future, although this may depend on the water tariff.

3.4 Effects of the Tsunami on Coastal Groundwater

Sri Lanka has a coastline of approximately 1,660 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 or went missing, and many thousands were displaced by the flood waves and the extensive property damage. In addition, most of the natural ecosystem along the coast was destroyed and complete 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, had been damaged or destroyed. Many of them were left unable to provide water that was fit for human consumption or even 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 to 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., 2005, a few days after the tsunami, the contaminated wells had COD levels of 128 mg/l, total and fecal coliform levels exceeding 30 and 7 CFU/100 ml, and conductivity levels of over 3,000 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 efforts 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 caused potential 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. *Issues relating to Alternative Water Resources to Groundwater*

As explained, both the study areas of Kandy and Colombo are blessed with plenty of rainfall and surface water. But, when one considers their variations over space and time, further analysis is required to ensure sustainability. Hence, during this study rainfall and surface runoff data in the two study areas were closely investigated to identify the surface water issues and the possibility of rainwater harvesting as an alternative water source for domestic use.

4.1 Surface Runoff Issues

Since there are many concerns with the existing groundwater sources, assuming the entire future water supply requirement in the two study areas is to be satisfied with surface water, the required minimum river runoff volumes to fulfill a) the full development water supply demand level (water provided to entire population) and b) planned water supply demand (what is planned in the water supply Master Plan Documents) for year 2025 was estimated.

Colombo: The estimated river flow requirements to satisfy the full development water supply demand and planned water supply demand in Colombo study area is tabulated in table 15 below. Though there are previous study data available on salinity control at Ambatale (river water intake), our investigation shows that the minimum river flow (environmental flow) requirement for salinity control downstream of Ambatale is estimated at 30 m^3/s. Analyzing the available Kelani flow data given in table 8 with the required minimum demands in table 15, it is obvious that satisfying demands, especially during dry weather low flow periods, can create salinity problems at the Ambatale water treatment plant. During recent years on a few occasions, the Ambatale water treatment plant had to be closed due to high salinity levels. Knowing this, a salinity barrier (barrage) across the river has been proposed. However the estimations in table 15 have not taken into consideration any salinity controls in existence. Therefore, if a salinity barrier is constructed, the minimum environmental flow requirement downstream of Ambatale will be less than that considered here.

Considering the past 40 year Kelani River discharges at Ambatale, an analysis was done to determine the reliability of daily available average flows in the river to satisfy the future expected demand in the Colombo study area. The obtained reliability percentages for this case are tabulated in table 16 below. The reliability values show that Kelani River flow can satisfy the Colombo study area year 2025 full development demand 79.7% of the time and planned supply demand in year 2020 by 90.8% of the time.

Table 15. Minimum Surface Water Requirements to Satisfy Future Demand in Colombo

Full Development Demand	**Water demand/(million m^3/month)**			
	2001	**2005**	**2015**	**2025**
Water demand	46.4	50.3	61.3	74.7
Environmental flow to salinity control	77.7	77.7	77.7	77.7
Total required flow	124.2	128.03	139.04	152.46

Planned supply demand	**Water demand/(million m^3/month)**		
	2001	**2010**	**2020**
Water demand	24.5	26.3	28.9
Environmental flow to salinity control	77.7	77.7	77.7
Total required flow	102.2	104	106.6

Table 16. Percentage Reliability of Kelani River to Satisfy the Future Water Demands in Colombo

Demand	2001(%)	2005(%)	2015(%)	2025(%)
Full Development Demand	85.8	84.9	82.4	79.7
	2000(%)	2010(%)	2020(%)	
Planned Supply Demand	91.8	91.1	90.8	

Kandy: The estimated river flow requirements to satisfy the full development water supply demand and planned water supply demand in Kandy are tabulated in Table 17 below. Here the irrigation requirement at Polgolla is a variable depending on the demands in the command areas. According to the NWS&DB "Kandy District Water Supply Development Program" of 2002 (Master Plan Document), the minimum recharge requirement (Environmental Flow) through the Polgolla dam is 4.2 m^3/s and the minimum diversion requirement through the Polgolla tunnel is 14 m^3/s, in February and March and the maximum diversion requirement through the Polgolla dam in June is 36 m^3/s.

Table 17. Minimum Surface Water Requirements to Satisfy Future Demand in Kandy

Full Development Demand	**Water demand/(million m^3/month)**			
	2001	**2005**	**2015**	**2025**
Water demand	5.2	5.4	6.0	6.7
Diversion water at Polgolla maximum	93.3	93.3	93.3	93.3
minimum	36.3	36.3	36.3	36.3
Environmental flow	10.9	10.9	10.9	10.9
Total required flow maximum	**109.4**	**109.6**	**110.2**	**110.9**
minimum	**52.4**	**52.6**	**53.2**	**53.9**
Planned supply demand	**Water demand/(million m^3/month)**			
	2000	**2015**	**2025**	
Water demand	2.0	3.1	3.6	
Diversion water at Polgolla maximum	93.3	93.3	93.3	
minimum	36.3	36.3	36.3	
Environmental flow	10.9	10.9	10.9	
Total required flow maximum	**106.2**	**107.1**	**107.8**	
minimum	**49.2**	**50.1**	**50.8**	

Analyzing the available Mahaweli discharges given in table 8 with the required minimum demands in table 17, it is obvious that satisfying the demands, especially during dry weather low-flow periods, can be a major issue at present and also in the future. Hence, considering the past 40 years of Mahaweli River discharges at Peradeniya, an analysis was done to determine the reliability of daily available average flows in the river to satisfying the future expected demand at Kandy. The obtained reliability as a percentage for this case is tabulated in table 18 below. The reliability values show that Mahaweli River flow can only satisfy the diversion demand at Polgolla and the Kandy study area year 2025 full development demand 68.8% of the time and planned supply demand 70.6% of the time. Further, the same analysis based on average monthly discharge gives the lowest reliability of 32% during February and maximum of 100% in November. Therefore it is vital to use the existing reservoirs at both upstream (Kotmale) and downstream (Polgolla) to control the flow to meet the future demands.

Table 18. Percentage Reliability in Mahaweli River to Satisfy the Future Water Demands in Kandy

River	2001(%)	2005(%)	2015(%)	2025(%)
Full Development Demand	69.8	69.7	69.3	68.8
Planned Supply Demand	72*	-	71.1	70.6

** Year 2000 demand*

4.2 Surface Water Quality Issues

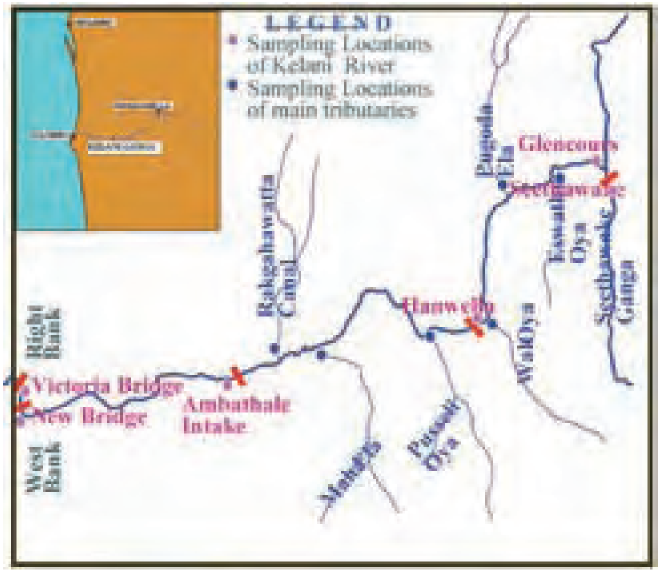


Figure 10. Water Quality Monitoring Points in Kelani River Colombo

Source: Hearth and Amerasekara, 2004

Colombo: The other major setback using the surface water sources in the two study areas comes from pollution issues. The water quality variation of the Kelani River was analyzed at several locations both upstream and downstream of Ambatale, as indicated in figure 10. The rapid development occurring in this region during the last two decades is contributing a substantial pollution load to the Kelani River. The upstream area of the Ambatale intake is congested with urban centres, industries and agricultural lands. According to the Danish Hydraulic Institutes' estimations in 1999, the urban pollutant load during dry season ranges from 150 – 650 kg/day of BOD. The urban load and per capita waste generation is much higher in the downstream of the Ambatale river intake. The total load is estimated to be about 4,000 kg/day of BOD below the water intake. The major wastewater generating industries upstream of the river intake include raw rubber factories, textile industries, beverage factories, rubber latex factories, milk food industries, steel manufacturing factories, plywood factories, fertilizer manufacturing factories and industries within the Biyagama Export Promotion Zone. These industries are estimated to discharge about 1,000 kg/day of BOD into the Kelani River. The petroleum refinery, chemical industries (soap, detergents, and pharmaceuticals) and Lindel industrial estate downstream of the Ambatale intake discharge about 2,000 kg/day of BOD (Danish Hydraulic Institute, 1999). Referring to the land usage in the basin, it is expected that the run-off of fertilizer, from tea lands in the upper catchment and from rubber and paddy lands in the mid-catchment, is the principal source of nutrients into the river. The current application of Nitrogen and PO_4 as fertilizer is estimated to be about 6,900 million tons and 1,920 million tons/year, of which 4,000 million tons and 845 million tons are applied to tea, 2,000 million tons and 370 million tons to paddy and 500 and 650 million tons to rubber, respectively (Danish Hydraulic Institute, 1999).

Recent water quality in the river is tabulated in Table 16. The data show heavy pollution. The dissolved oxygen (DO), 5-day biochemical oxidation demand (BOD_5) and chemical oxidation demand (COD) levels at Ambatale and downstream of Ambatale were often in excess of the Sri Lankan inland surface water standard required for bathing or for drinking with complete treatment (current standards are 5 mg/l for DO, 4 mg/l for BOD_5, and 20 mg/l for COD respectively). Further, in most tributaries and the lower river estuary very low DO values (occasionally below 1 mg/l) and low BOD_5/COD indicate high industrial waste disposal. Further, the observed levels of dissolved Cr and dissolved Pb too indicate extensive industrial pollution, especially in the estuary area. However, the nutrient levels observed in the river are smaller than anticipated considering the loads of applied fertilizer in the catchment. Nonetheless the available nutrient concentrations are far more adequate for eutrophication to occur (Muller, 1999) and periodic algal blooms were observed in the shallower areas, especially in stagnant waters during low-flow periods. Also, the observed high coliform counts well over 15,000 CFU/100 ml in almost all monitoring stations show the high degree of urban sewage discharge, too.

The chloride content shows high variations, especially in the lower reaches. The main reason is seawater intrusions as a result of low river flows and sand mining. Occasionally this saline water even reaches the Ambatale water supply intake during prolonged droughts and, as mentioned, interrupts the water supply to the Colombo area. Therefore, this saline-water intrusion can be a major problem in the future as many recent studies have shown that rainfall, compared to few decades back, has significantly reduced, with the lengths of the dry periods having increased and the lengths of wet periods having decreased all over the country (Ratnayake and Herath, 2005).

Given the current and future importance of the Ambatale intake, the construction of a salinity barrier appears to be a priority to protect the water supply during prolonged dry periods. The flow at intake is currently protected from large industrial effluent discharges by a government policy not to site such industries above Ambatale. However, the river water quality should be monitored and modelled so as to extend the sustainability.

Table 19. Water Quality Data along the Kelani River

Location		BOD (mg/l)	COD (mg/l)	NO_3^- (mg/l)	DO (mg/l)	PO_4^{3-} (mg/l)	E-Coli (cfu/100ml)
Sri Lankan Standard	Maximum Permissible	4	10 – 20	-	5	-	0
Hanwella	Average	2.26	20.1	0.24	6.75	0.03	5,083
	Range	0.4 – 7.2	10 – 52	0.01 – 0.91	2.6 – 8.7	0.01 – 0.1	230 – 16,000
Kaduwela	Average	1.87	16.4	0.25	-	0.11	-
	Range	0.4 – 5.8	4.0 – 46	0.01 – 0.67	-	0.01 – 1.09	-
Ambatale	Average	3.2	20.8	0.26	6.63	0.03	3,702
	Range	0.4 – 9.2	10 – 50	0.01 – 0.86	4.9 – 8.3	0.01 – 0.25	400 – 16,000
Victoria bridge	Average	3.06	111	0.22	5.53	0.02	11132
	Range	0.6 – 6.4	7.5 – 359	0.01 – 0.72	0.8 – 7.5	0.01 – 0.13	800 – 16,000

Source: Hearth and Amerasekara, 2004

Kandy: Since Maheweli River is the only source of surface water available in the Kandy study area, water quality variations in this river were analyzed during this study (Figure 11). Land cover in the upstream catchment of Mahaweli River is mainly of forestland, tea cultivation and human settlements. Therefore urban wastewater and agricultural runoff are the main sources of pollution from the upstream area. However, most pollution to Mahaweli River comes not from upstream but from the surrounding areas of Kandy. The tributaries from Peradeniya to Polgolla bring this wastewater into the main river. Of these, the "Meda Ela"—having a catchment area of 19.31 km^2—is adding most of the pollutants into the Mahaweli River. This urbanized sub-catchment that covers a substantial part of Kandy City, mainly consists of commercial and industrial activities, hospitals and urban clusters that have direct sewerage outlets to the stream. The other considerable pollution comes from the largest tributary, "Pinga Oya." Its catchment too is fairly urbanized. The following table, table 20, shows a summary of the past 15 years' water quality data for Mahaweli River and its tributaries.

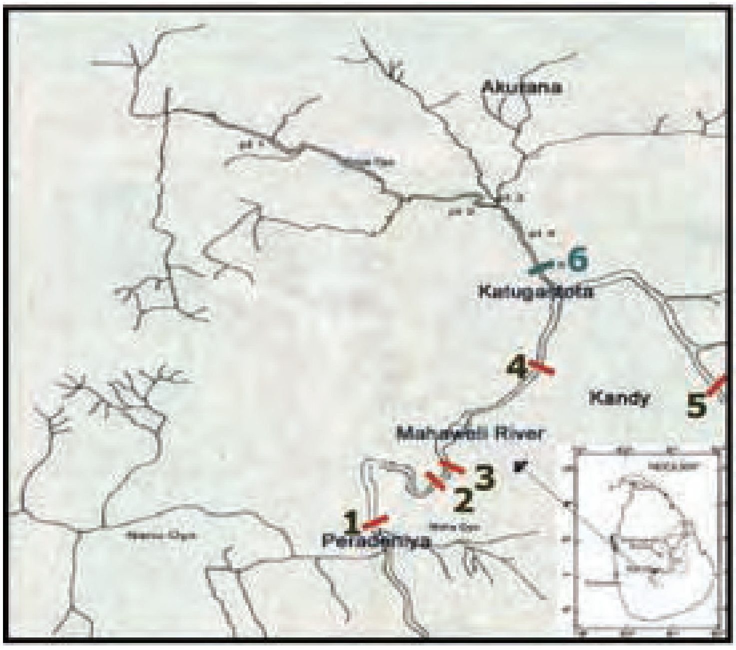


Figure 11. Water Quality Monitoring Points in Mahaweli River Kandy

Source: Herath, 2003

At Peradeniya (before entering the Kandy City limits) the main stream of Mahaweli River has relatively good water quality, yet the tributary confluence from Peradeniya to Polgolla has higher pollutant strengths. Higher amounts of coliform and nutrients are signs of human waste contamination. Among the three tributaries shown in the table; the Pinga Oya and Meda Ela brings the most polluted water into the Mahaweli River. Apart from the sewerage disposal, direct solid waste dumping also takes place in the tributary catchment areas and muddy soil, with a great deal of polyethylene waste is observed at the Pinga Oya confluence. The polythene deposits on the riverbed reduce the infiltration and increase the surface water runoff, which will cause flash floods and dry periods. The water quality at Polgolla shows the impact of the Kandy City region on the quality of water in Mahaweli River. Fortunately the most polluted stream confluence is located downstream of the water supply intakes.

Table 20. Average Water Quality Data of Mahaweli River, Meda Ela and Pinga Ela

Location		BOD (mg/l)	DO (mg/l)	E-Coli (CFU/100ml)	NO_3- (mg/l)	PO_4^3- (mg/l)
Sri Lankan Standard	Maximum Permissible	4	5	0	10.0	2.0
Mahaweli River	Average	3.2	6.4	50	1.42	0.20
(At Peradeniya)	Range	3.0 – 4.2	5.3 – 7.5	10 – 120	0.17 – 4.2	0.01 – 1.5
Maha Oya	Average	3.06	5.2	450	0.65	0.06
(A tributary)	Range	0.6 – 6.4	4.3 – 6.2	50 – 850	0.08 – 1.3	0.01 – 0.43
Meda Ela	Average	8.4	2.4	3500	2.24	0.22
(A tributary)	Range	3.2 – 15.8	1.0 – 4.6	900 – 9000	0.94 – 6.02	0.02 – 2.59
Pinga Oya	Average	5.2	3.87	1400	0.95	0.18
(A tributary)	Range	3.4 – 9.2	1.5 – 6.2	9 – 7500	0.08 – 4.4	0.01 – 2.85
Mahaweli River	Average	4.6	3.4	420	2.36	0.03
(At Polgolla)	Range	3.2 – 6.4	1.0 – 4.9	160 – 960	1.32 – 4.97	0.01 – 0.1

Source: Herath, 2003

4.3 Rainfall Issues

Since there is adequate rainfall available in the two study areas, rainwater harvesting (RWH) can be an attractive alternative to surface/ground water. However, issues such as rainfall reliability, its storage and quality, consumer acceptance, etc., are very important for the future success of rainwater harvesting. Therefore, during this study the necessity for rainwater harvesting, rainfall variations, quality of rainwater comparison with drinking quality standards and the required infrastructure requirements were studied. Further, the future success of the proposed “Rainwater Harvesting Policy and Strategies” was investigated using a questionnaire survey in the Kandy study area.

Assuming an average family size of 5 and a minimum water requirement of 40 l/person/day for basic needs, the required tank capacity and the necessary roof area for rainwater harvesting were calculated, taking into account the past 40 years’ rainfall data in Kandy. The study obtained the minimum tank capacity as 6,000 l and roof area of 134 m^2. It was estimated that this storage facility using low cost materials such as ferro cement would cost around 200-250 USD. With the help of these findings, a questionnaire survey was conducted in two urban areas (a total of 22 samples) and four peri-urban areas (51 samples). The results showed that the preference for RWH potential in urban areas is very low but most people in peri-urban areas are keen on RWH. Also, most people preferred rainwater only for secondary purposes such as washing, gardening, etc. Although 80% of people with a piped water supply were not keen to harvest rainwater for basic needs, over 80% of people who do not have a piped water supply were very keen to harvest RW. However one major problem identified during this survey is the extent of available roof area, where over 60% roofs were below 133 m^2. Also awareness and knowledge on rainwater harvesting were very poor among the respondents. Therefore a program should be implemented to popularize rainwater harvesting within the society.

5. Policy Responses and Future Challenges

Despite the fact that Sri Lanka is blessed with a good water resource, when one considers its variations over space and time, a proper management strategy for its sustainability is needed. Additionally, there have been a number of recent warning signals pointing to heightening 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. Therefore, in this section, the available policy instruments and the existing institutional arrangements are analyzed from the perspective of how they could respond to the immediate challenges posed to the water resources of the country in realizing their ultimate sustainability.

5.1 Available Policy Framework and the Institutional Arrangement

As mentioned, 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. Of these the WRB and the NWD&DB are playing a much more active role in the water sector today compared to the ADA. Further, the Central Environmental Authority, (CEA) though not directly involved, is related to water conservation in the country as it has the mandate to prevent the pollution of the environment, including water environment. The main functions of these water-related institutions could be listed as follows:

Water Resources Board: The WRB was established in 1964 by an Act of Parliament to control, regulate and develop—including the conservation and utilization of—water resources of Sri Lanka. Further, it was tasked with the promotion, construction, operation and maintenance of water-related schemes (e.g. irrigation, drainage, flood control and hydraulic power, etc.) and the prevention of the pollution of rivers, streams, and other watercourses. The WRB also was given the authority to formulate national policies relating to the control and use of water resources of the country with the objectives of:

i. Multi-purpose development and use of water resources;
ii. Short-term and long-term provision of water resources;
iii. Disposal of sewage and industrial wastes;
iv. Preparation of the comprehensive and integrated plans for the conservation, utilization, control and development of the water resources;
v. Coordination of the activities related to surveys of basic data and other investigations relating to river-basin and trance-river-basin development projects, soil classification, and the hydrological, geological and other similar aspects of the use of lands; and
vi. Any other suitable measures to be taken by the Government for the proper control and economic use of water.

National Water Supply and Drainage Board: In 1974, the NWS&DB was established and given the responsibility to develop, maintain and provide a proper, safe water supply for public, domestic and industrial purposes and to establish, develop, operate and maintain the necessary wastewater disposal systems in the country. With this Act, the NWS&DB was given freedom to: buy and sell water; develop, operate, and investigate; collect necessary data and document the information related to water supply and wastewater disposal; owning or leasing tangible and intangible property; conducting research related to the supply of piped water and wastewater services, its developments and information related to the operation and maintenance of such projects, etc.

Central Environmental Authority: In 1980, the Central Environmental Authority (CEA) was established by an Act of Parliament for the protection of any portion of the environment against waste discharges. Further, this Authority was entrusted to conduct surveys, to conduct, promote and coordinate research on any aspect of environmental degradation, develop criteria and specify standards for environmental protection and powers to undertake investigations and inspections to ensure the regulations related. Again, this Act was amended in 1990 such that many specified large-scale projects need necessary approval from the CEA for their construction and operations. This included groundwater-based water extractions but limited only for projects that exceed daily extractions above 500,000 m^3.

5.2 Proposed National Water Policy

The origins of Sri Lanka's recent water policy development may be traced back to the recommendations given by the Presidential Land Commission of 1985, who perceived their role not only as a 'land commission' but also to some extent as a 'water commission.' This commission stressed the need for developing a 'National Water Master Plan' as they have identified many problems with the existing institutional arrangement available for managing the water resources of the country. Therefore, on these recommendations, the Government of Sri Lanka with technical assistance from the Asian Development Bank formulated the draft proposal 'National Water Resources Policy' through the Water Resources

Secretariat (WRS), which is a new institution set up especially for this purpose. The prime objective of this policy was to strengthen the capacity of the Sri Lankan Government to manage water resources in a sustainable, participatory and transparent manner. In these new proposals, some major deficiencies in the present water, as well as groundwater management setup, were identified. The major problems in groundwater management identified in this water policy can be listed as (National Water Policy – Draft, 2000):

i. Ownership, and therefore management responsibility, of the groundwater is not clearly defined in legislation.
ii. Responsibility for investigation into and development and regulation of groundwater is not formally assigned to any agency.
iii. There is neither a coordinated groundwater information program nor a proper groundwater planning system.
iv. 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.
v. There is no legal basis for groundwater allocation.
vi. There is no public information or awareness program regarding groundwater.

However, with the change of government in 2001, the proposed water policy had to go through significant changes and, in 2002, a major revision was made to the policy formulated in 2000. This policy is still in the draft stages, as the government changed again in 2004.

5.3 Stakeholders' Meeting

During this study a stakeholders' meeting on "Sustainable Water Management Policy: Ground and Surface Water Resources" was organized in February 2007 to discuss and identify the following:

i. The water development and management practices in the past, and their adverse impacts;
ii. The tools and policies available for the mitigation of the adverse impacts;
iii. The important technical inputs and policy issues that need to be addressed to improve management of water resources; and
iv. To develop guidelines and strategies for improved policies for sustainable water resources management.

The meeting was well attended, with over 30 participants from various water-related agencies. At the end of the meeting many suggestions were put forward for achieving the ultimate objective of sustainable water management in the country. Based on the discussions held during the meeting, a list of recommendations was formulated. The main recommendations made in this meeting can be summarized as:

i. Available policy is adequate, but proper implementation is necessary to overcome the present ground and surface water problems.
ii. Crevice groundwater should not be recommended for large-scale abstractions.
iii. Need to raise awareness among the public on water related issues.
iv. Proper ground and surface water monitoring is necessary.
v. Dialogue on the proposed water policy should be started immediately.

5.4 Policy Gaps Identified during this Study

In 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 water and the groundwater resource. In the present set up, as there are several agencies involved in groundwater development; even though the WRB is responsible for managing the overall water resources, due to confusion in deciding who should manage the groundwater resources, policies are been implemented poorly with nobody taking responsibility for managing the groundwater resources. Often this can be one of the main reasons for many of the present groundwater problems. Furthermore, a lack of adequate financial and trained human resources within these agencies has also seriously affected the present groundwater management.

As described in a previous section, data from the construction stage of deep groundwater wells in the Kandy study area shows that only few hard rock crevice aquifers have reasonable yields. Further, many water supply schemes in Kandy (as well as in Colombo) that were based on successful boreholes drilled in the hard bedrock have run into several problems due to a lowering of both the water levels and the yields. Hence, past experiences in Kandy and Colombo clearly show that the amount of groundwater available in this type of hard rock aquifer is very limited and hence may be suitable only for rural, small-scale water supply projects and not for large, urban water supply schemes. Therefore it is the correct time for the Authorities to formulate proper policy guidelines in this regard and should be made available very soon. The NWS&DB is already in the process of replacing the problem-prone groundwater scheme with surface water schemes.

Incidents of this nature, together with the other groundwater problems experienced in the recent past, suggest that groundwater development in urban areas 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 investigation programs. Funding for this may come by establishing a fund through levying a groundwater charge for heavy use. Further, as there are no present programs available for monitoring either 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 are often poorly understood and over-exploited by both the decision-makers and the users of the groundwater.

Further, 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 may periodically be issued, 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 understandable 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.

5.5 Policy Recommendations

Based on the findings of this study, the following list of policy recommendations can be suggested to overcome the issues related to the water resources of Colombo and Kandy study areas:

(1) Proper Management of the groundwater resource

a. Main issues

i. Current Groundwater ownership is with the individuals, but changing ownership is a critical and sensitive issue. This was one of the main reasons for the failure of the proposed water policy.

ii. Poor Groundwater management/governance due to multiplicity of institutions
WRB Act – empowered the WRB by law to control, regulate and develop, including the conservation and utilization of water resources of Sri Lanka (not practiced however, as available legal provisions are confusing) but, on the other hand the NWS&DB Act has given a mandate to the NWS&DB for the development of water supply schemes. Complexities such as these have resulted in nobody taking the responsibility of managing the groundwater resource.

iii. Limitations in the existing groundwater resources
It is vital to limit the hard-rock groundwater resource to be used in limited applications and should base extraction limits through proper scientific investigations

b. Recommendations

Identify and demarcate groundwater sensitive areas in each administrative division

Regulation only in sensitive areas with the following proposed priority scheme

i. Top priority for domestic purposes with an upper per capita limit

ii. Regulate other uses with a pre-determined priority basis (case by case)
iii. Non-sensitive areas – no regulation necessary but identify/keep records on heavy uses

Limit hard rock groundwater use only to small scale/individual water supply.

Encourage surface water use and rain water harvesting, especially in sensitive areas.

Establish principals for groundwater management by issuing proper guidelines for proper constriction, the safe and sustainable exploitation and use of groundwater for all types of aquifers.

(2) Need for Regular Monitoring and Investigation Programs

a. Main Issues

At present there are no reliable, continuous or ongoing monitoring data available on groundwater. This has made it difficult to determine causes for groundwater failures in the study areas and also to identify groundwater behavior trends in aquifers, making it a major setback in managing the resource (e.g., groundwater problems in Kandy).

b. Recommendations

Establish a system for collecting groundwater-related data

Make WRB responsible for this task (already empowered by an Act of Parliament)

(3) Need for a Well-coordinated and Reliable Information System

a. Main Issues

Although some groundwater studies have been undertaken in the past, even this data is scattered or misplaced. Also, different organizations collect and keep data essentially only for their own use. Hence, a proper database is necessary to collect these scattered data, to manage them and to make them readily accessible for all.

b. Recommendations

Establish a centralized information system with data readily available to any interested party.

Demand-driven research, assessment and monitoring programs 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.

(4) Conflicting in Water Allocation Rights

a. Main Issues

According the present policy set up:

i. WRB - Has the right to Control Regulation and Development of all water resources of Sri Lanka
ii. NWS&DB – Not clearly state their rights but use water for water supply schemes without the permission from WRB
iii. Mahaweli and Irrigation Departments – Play both the roles of the regulator and user for irrigation in some important river basins, including the Mahaweli River
iv. Ceylon Electricity Board – Permission is granted (and high priority given) by an Act of Parliament to use water for hydropower generation. These types of priority listings have led to many confusions and conflicts in the past over who has the priority/right over whom to use water (e.g. Salinity intrusion into the Colombo water treatment facility as water in the Kelani River is regulated at upstream reservoirs for hydropower generation)

b. Recommendations

Establish a clear priority policy for water allocation

Establish a proper mechanism to manage water use between different sectors

A proper compensation scheme for the lost opportunity (e.g., if irrigation water rights are lost due to water taken for drinking water supply, proper compensation for farmers, etc.)

(5) Pollution Prevention

a. Main Issues

At present, almost all surface water sources in urban areas are highly polluted. Further, the shallow groundwater resources in urban areas are often contaminated with coliform and nutrients. One major reason for these failures is shortcomings in the present management structure. As explained earlier, the Central Environmental Authority (CEA) was established for the protection of any portion of the environment against waste discharges, but also the WRB has provisions from its Act for prevention of the pollution of rivers, streams and other watercourses. Even though there are two agencies available to prevent water pollution, due to the following reasons, prevention has not being effective so far:

i. lack of stringent legal instruments to punish polluters
ii. lack of standards for coliform, nutrients, etc., discharges
iii. failure to implement the laws especially for GW contamination (WRB)
iv. influence from local politicians (local government)
v. no coordination between the two organizations

b. Recommendations

Strict enforcement of the present law with enhanced legal provisions

Introduction of new discharge standards covering all pollutants

(6) Other Issues and Recommendations

In addition to the above five main recommendations, this study identifies the following, also, as important recommendations for sustainable water resources both in Colombo and Kandy:

i. Proper definition for safe drinking water and a proper monitoring mechanism is necessary, as at present there is no clear definition for safe drinking water in Sri Lanka and, further, no proper guidelines for maintenance of such supply or sources.
ii. Reduction of non-revenue water, which are very high in both study areas: 40% in Colombo and 36% in Kandy.
iii. Awareness raising and stakeholder (especially public) participation in decision making
iv. 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 or rainwater harvesting when it is available and to save groundwater for use during periods when there is deficient surface/rain water.
v. Initially, a registration program should be started for heavy groundwater users. Thereafter, establish a well-licensing program to track groundwater development.
vi. 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. It is therefore necessary to have strong participation from the community and water users, and to promote awareness to facilitate the planning and management of groundwater resources.
vii. 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. As it is considered impractical to regulate these small wells through water entitlements, 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.

6. Acknowledgments

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CHAPTER 3-6

Groundwater Quantity Management in Osaka City

1. Background to 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 (Osaka City 2006). 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).

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 USD, more than the gross national product of either Hong Kong or Thailand.

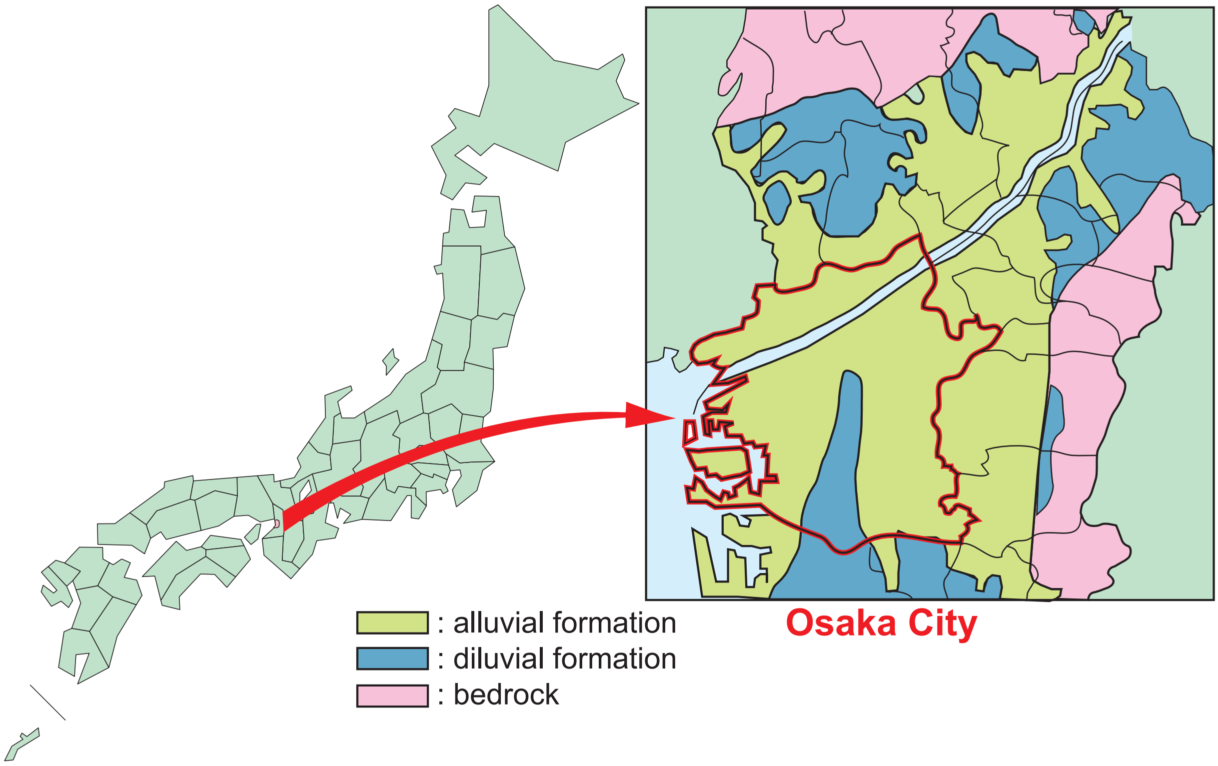

Figure 1. Location of Osaka and its Geological Characteristics
Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993.

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/year, when 82% of abstraction was used by the industrial sector and the remaining volume by buildings. In the industrial sector, the food industry consumed groundwater the most (33%), followed by the paper and pulp industry (21%) and the chemical industry (18%)[1] . 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).

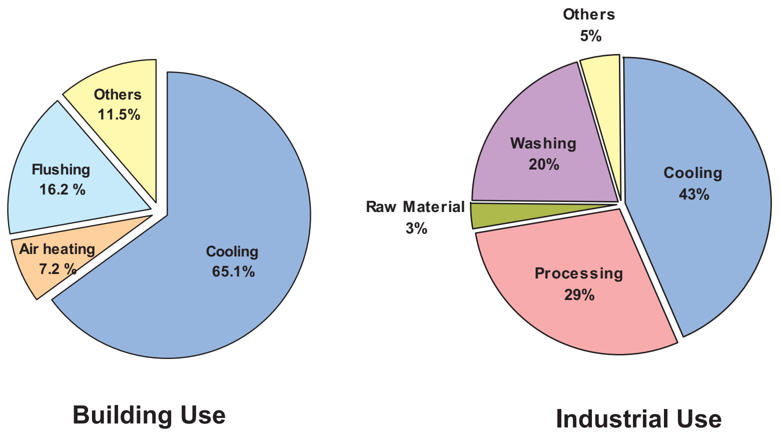

Figure 2. Groundwater Use in Osaka by Type of Use, 1962

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

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[1] According to a study in 1960, chemical industries consumed 32 percent of total industrial groundwater abstraction followed by food industries (22 percent) and paper industries. The drop of groundwater use of chemical industries from 1960 and 1962 was the result of introduction of more strict abstraction control measures in 1962.

2.2 Problems Caused by Excessive 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.

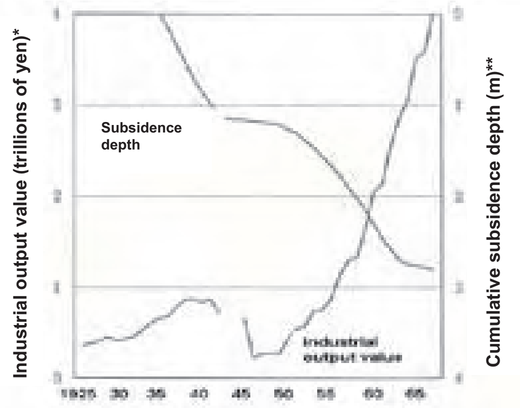

Figure 3. Land Subsidence and Industrial Output Value in Osaka
Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993.
**In 1965 prices. **At Nishi-4 (Torishima, Konohana-ku)*

The increase in the magnitude of land subsidence resulted in various hindrances to the development of the city. As the land base sank, the height of dykes became lower and they lost their ability to protect the city from flooding. This resulted in a worsening of the negative impacts of flooding, especially during typhoons. The city had to spend about 2.5 billion USD (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.

3. *Policy Response*

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.

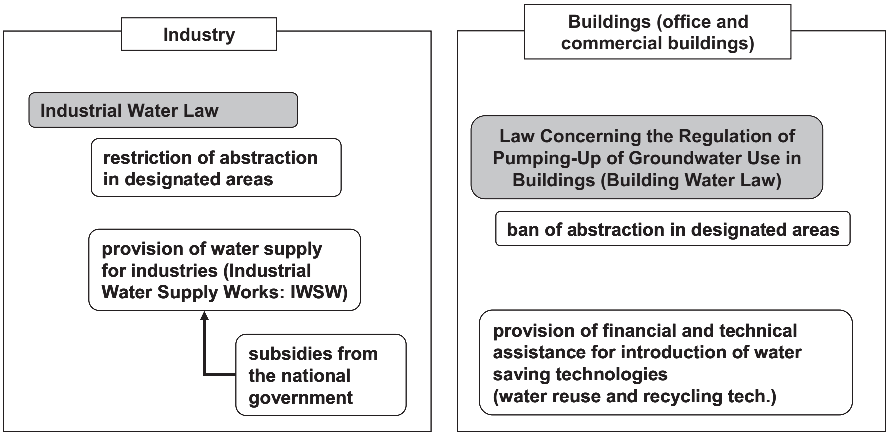

Figure 4. Outline of the Types of Groundwater Management in Osaka

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 Pumpingup 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 ordinancedesignated 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).

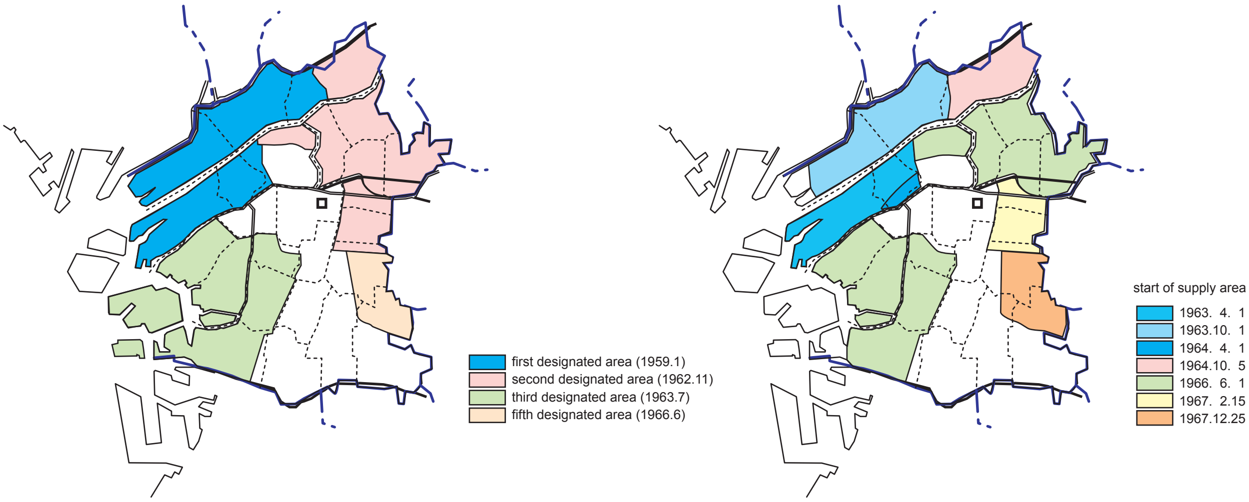

Figure 5. Areas Designated under the Industrial Water Law and Provision of Industrial Water Supply Works
Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1971.

The IWSW expansion project was completed in December 1968 and covered all the designated area with 575,500 m^3/day of total capacity (Osaka City Waterworks Bureau 2005). The tariff of IWSW in Osaka in 1954, 6.8 JPY/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 JPY/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. This charging policy was criticized as a distortion of tariff structure and a barrier to promoting rational use of water in industrial sector (Simazu 1981).

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.

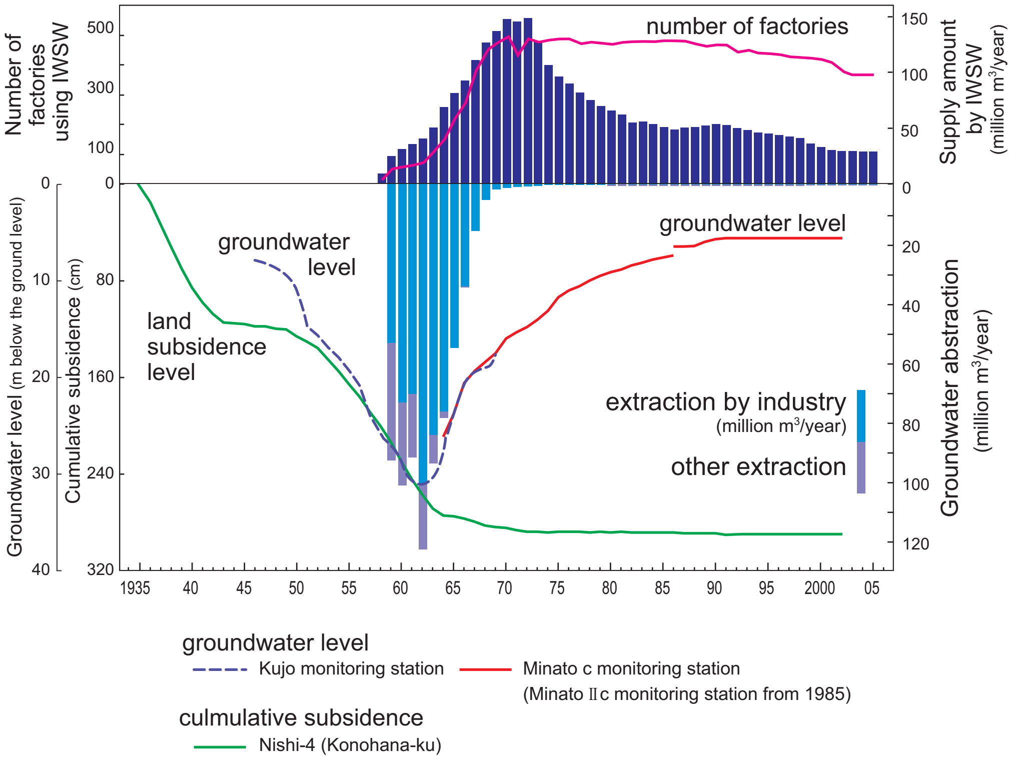

Figure 6. The Shift from Groundwater to Industrial Water Works for Water Supply in Osaka City
Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993. for land subsidence and groundwater level.
Osaka City Water Works Bureau 2005. for the data of industrial water supply works.

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

i. Land subsidence was monitored by the city government for more than three decades, which helped in policymaking.
ii. 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.
iii. The main users of groundwater were industries and large buildings, and therefore control measures focused on these two sectors.
iv. 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.

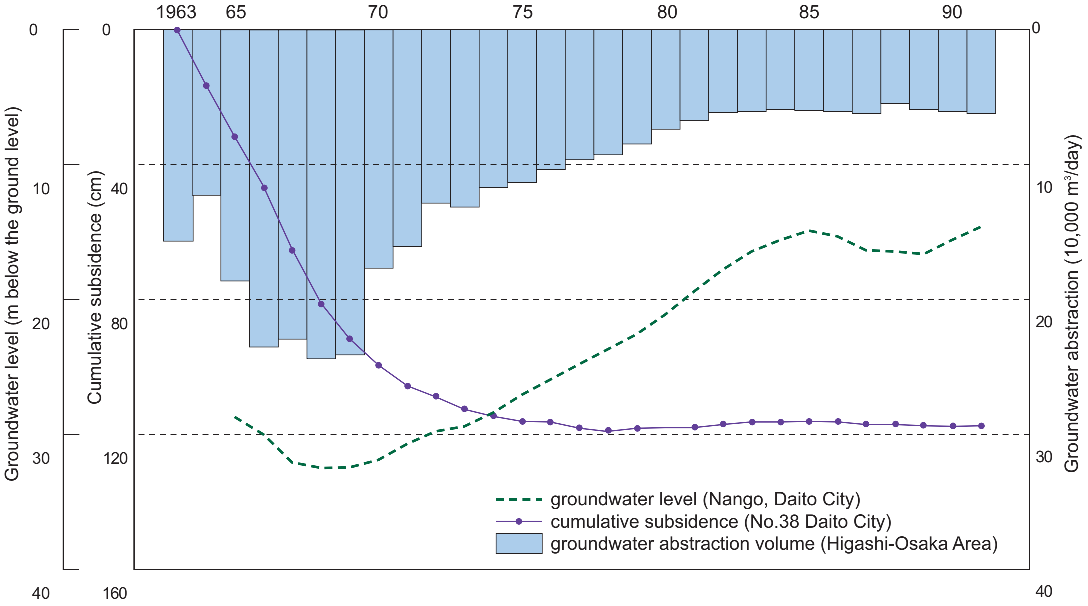

Figure 7. Cumulative Subsidence Depth and Drop in the Water Table in Higashi-Osaka
Source: Committee on Comprehensive Countermeasures against Land Subsidence in Osaka 1993.

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.

(1) Experience of Tokyo in Groundwater Quantity Management

Although the two national laws (Industrial Water Law and the Building Law) applied both in Osaka and Tokyo, it took more time in Tokyo to reduce groundwater abstraction. One of the reasons why it took time in Tokyo to reduce groundwater use is the limited availability of alternative water resources. As it was difficult to acquire the rights to river water use 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 instead of surface water, but industries hesitated to use it because of concerns about consistent water quality. In fact, IWSW using treated wastewater stopped their operation because of the quality of water they produced.

Another reason of the delay of groundwater use control is that the natural gas abstraction was a cause of groundwater abstraction in the Tokyo Bay Area. To cope with this, the Tokyo Metropolitan Government purchased the right of mining from the industries which abstract natural gas and stopped groundwater abstraction.

In addition, the Tokyo Metropolitan Government tried to promote reduction of groundwater use to request industries to rationalize groundwater use through the Pollution Control Ordinance issued in 1970. Under the groundwater use rationalization plan, groundwater users (mostly industries) with abstraction volume more than 1000 m^3/day were requested to reduce their use to the negotiated volume with the local government in 1975. In 1978, the request was extended to groundwater user with abstraction of 500 - 999 m^3/day and also to the groundwater users with abstraction of 250 - 499 m^3/day in 1981. The Pollution Control Ordinance also regulated smaller groundwater users who were not regulated by the national laws. Due to the efforts to rationalization of water use and more strict regulations to groundwater users by the local regulation, groundwater abstraction had been decreasing since 1970 in Tokyo.

(2) Hiratsuka's Experience

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/day in 1972 to about 50,000 m^3/day 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 JPY/m^3 for wastewater treatment, while the investment cost for water-saving technology was about 19.5 JPY/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.

(3) Water Recycling in Industries

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 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%, and the rate would be less than 40% 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.

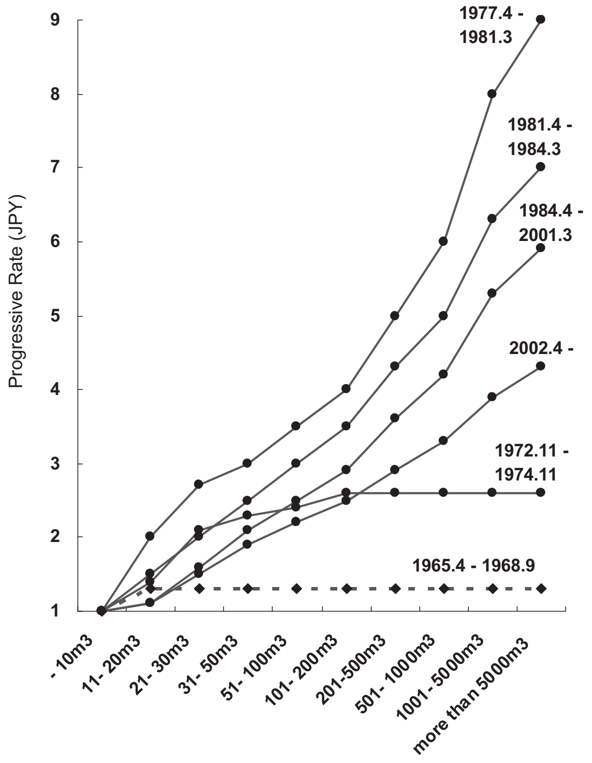

Figure 8. Progressive Rate of Sewage Charges in Osaka
Source: Takahashi 1992.

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 (BOD and COD) 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.

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 JPY (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. 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 mediumand 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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CHAPTER 3-7 Groundwater Quality Management -Tokyo-

1. Background to the Study Area

Tokyo is the capital city of Japan, and is the political and economic center. Tokyo has about 12.4 million of people and about 2,187.1km^2 of land, and is one of the most densely-populated cities in the world (5,660 persons/km^2). The population of the city is about 10% of the national population, and is concentrated in both the area of the 23 Wards and the Tama Area, as shown in the following map. The 23 Wards of Tokyo are the only special wards in Japan.

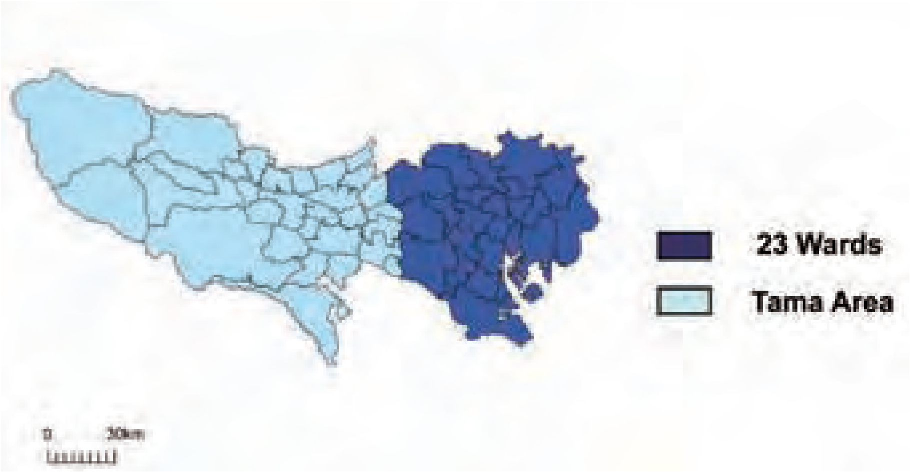

Figure 1. Map of Tokyo

Source: Digital Map 25000 (Administrative Boundary & Coastline), Geographical Survey Institute

As did Osaka, Tokyo enjoyed rapid economic growth from the 1950s. With the growth, people and factories gathered in the area and, therefore, much cultivated land was converted to residential or industrial zones. The number of people and industries rapidly increased until the 1970s and 1980s, though now the numbers of both people and industries have decreased or are currently stable.

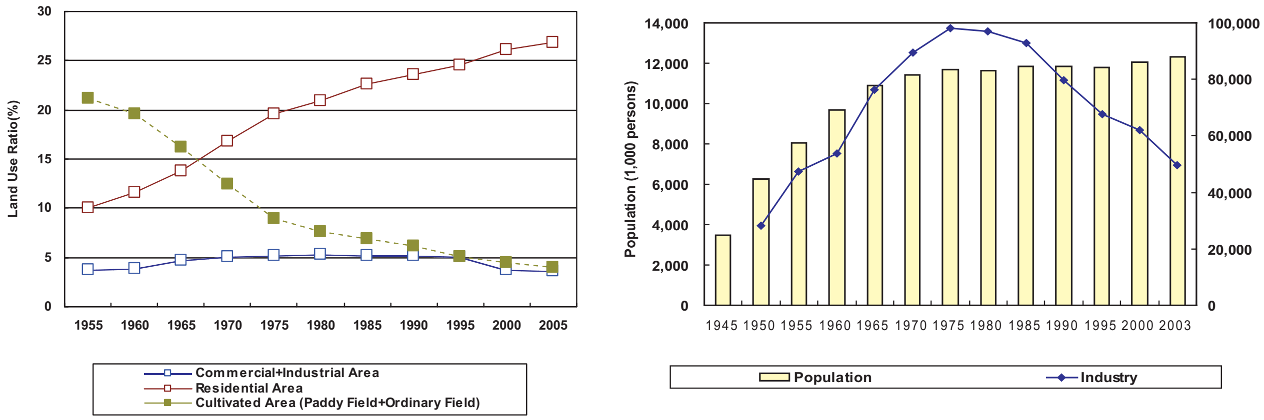

Figure 2. Land Use Change and Annual Change of Population and Industry in Tokyo
Source: Tokyo Metropolitan Government General Affairs Bureau 1947-2005, Ministry of Internal Affairs and Communications 1955-2005.

2. Groundwater Quality related Problems

Even though it has always been regarded as an important water resource, until the 1990's, groundwater quality in Tokyo was not managed systematically, as in other cities in Japan,. The reasons are as follow:

i. Although quantity related issues such as water table depletion and land subsidence have been major problems in Tokyo for decades, at the beginning the local government paid attention only to matters of quantity.

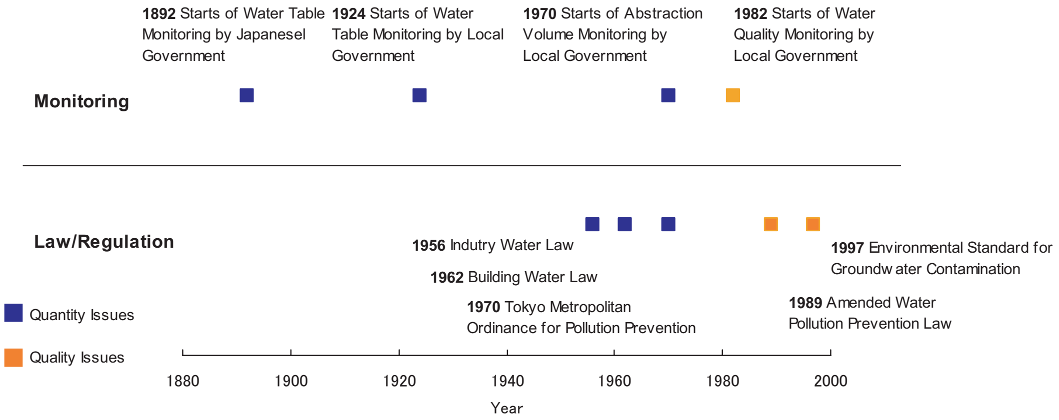

Figure 3. History of Groundwater Management in Tokyo
Source: Tokyo Metropolitan Government Environment Bureau 2006, Tokyo Metropolitan Government 1989.

ii. Because pollution of surface water of rivers, lakes and water in the gulf were considered more serious, the government prioritised mitigation or prevention measures for them. Therefore, the control of surface water were subjects only in "Law on Conservation of Public Water Body Quality" and "Law on Regulation of Industrial Wastewater" established in 1958 and "Water Pollution Prevention Law" established in 1970.

iii. Groundwater in Tokyo has been used mostly for industrial and domestic uses. Groundwater abstraction volume for industrial purposes decreased after enforcement of "Industrial Water Law" and "Building Water Law" that were intended to reduce groundwater abstraction for the mitigation of land subsidence. Groundwater was generally used for domestic purposes after treatment in water purification plants, and use of untreated groundwater by individual households is quite limited. Therefore, the groundwater quality was relatively easy to control for domestic use.

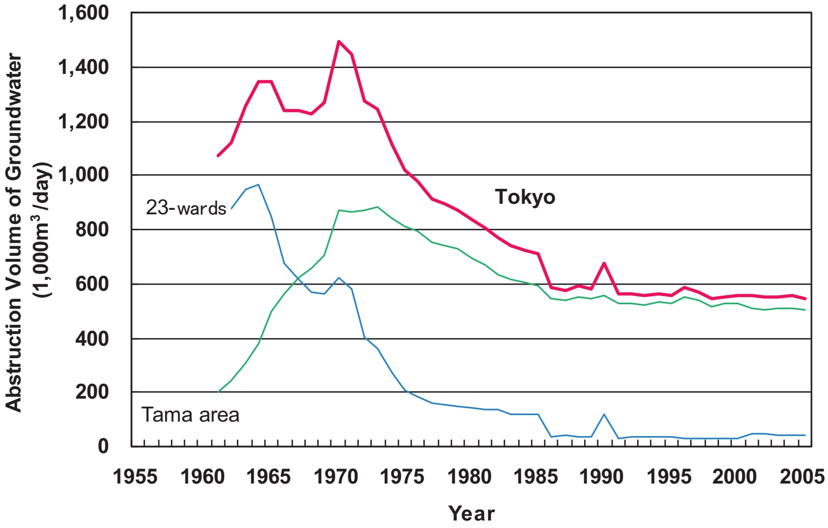

Figure 4. Annual Change of Groundwater Abstraction Volume in Tokyo

Source: Tokyo Metropolitan Government Civil Engineering Center 2006, Tokyo Metropolitan Government Environment Bureau 2006.

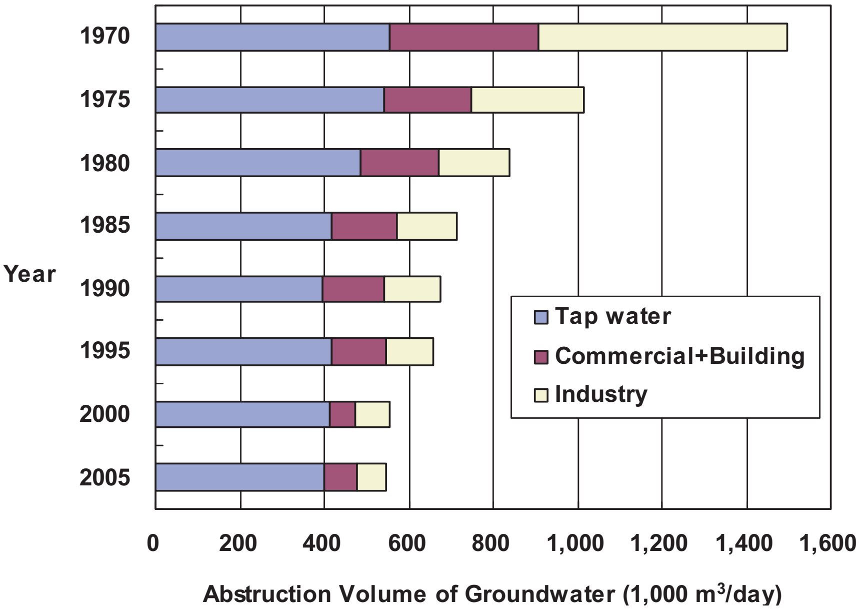

Figure 5. Beneficial Use of Groundwater in Tokyo

Source: Ministry of Health and Welfare, the Ministry of International Trade and Industry, the Ministry of Construction. 1971. Tokyo Metropolitan Government Environment Bureau 1976-2006.

iv. Sea water intrusion to groundwater was confirmed in coastal areas from the 1950's to the 1960's. Not only was the regulation on groundwater abstraction effective to some extent in the prevention of sea water intrusion, also groundwater use in coastal areas decreased due to the transition to surface water use. As a result, the chloride contamination of groundwater has been less acknowledged as a problem than it should be.

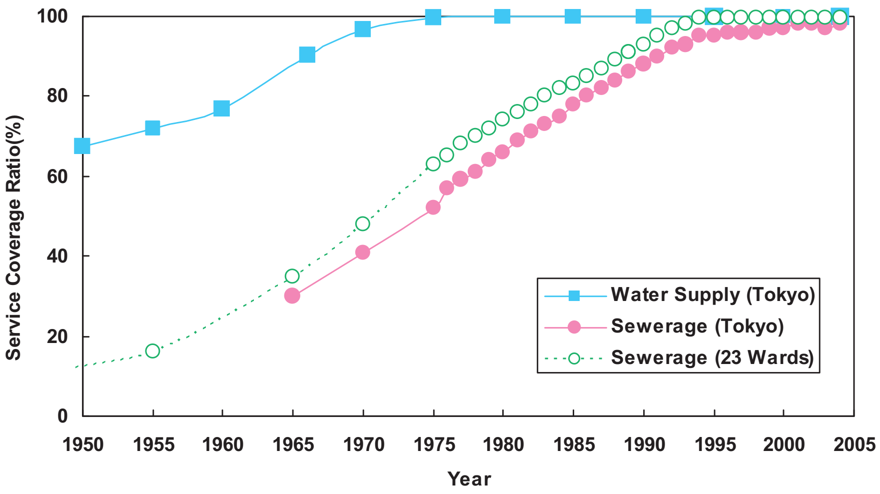

Figure 6. Service Coverage Ratio of Water Supply and Sewerage in Tokyo from 1950 to 2005
Source: Source: Tokyo Metropolitan Government 2004, Suido Sangyo Shimbun1940-2004

v. Sea water intrusion, pathogenic microbiological and nitrogen contamination from domestic wastewater or fertilizers were also identified in the past, but they were not considered to be serious problems, supposing that traditional pollution controls such as treatment at water purification plants or at sewerage plants would be effective.

Under the above background, groundwater quality was not monitored regularly until 1982 except in the case of groundwater for tap water use. However, because VOCs contamination occurred in the United States and in the Fuchu-district in Tokyo in 1981 and 1982, respectively, initiated by MOEJ in 1982, groundwater quality was investigated in the main cities of Japan, including Tokyo. The result of the survey clarified the existence of groundwater contamination, e.g. on VOCs, and led to mounting public opinion calling for its control. Especially, management of hazardous chemicals such as VOCs in industrial sectors was called into question by the public, because it was revealed that some factories regularly discharged wastewater containing VOCs into the ground.

3. Policy Response

In order to address groundwater pollution control at the national level, the “Water Pollution Prevention Law” was amended in 1989 and set regulations on groundwater quality management. As shown in the following figure, four elements of groundwater quality management were determined in the law, (1) implementation of regular water quality monitoring by provincial government, (2) prohibition of discharging hazardous wastewater into the ground by industry, (3) mandatory notification for establishment of facility treating hazardous materials (Notification by industry and examination by the governor), and (4) implementation of emergent measures for accidental groundwater pollution (Notification by industry and examination by the governor). Of the four policy measures, three are for the prevention of pollution, while the other one is for mitigation. In addition to those measures, in order to support these groundwater pollution policies, the Environmental Standard for Groundwater Contamination was established in 1997.

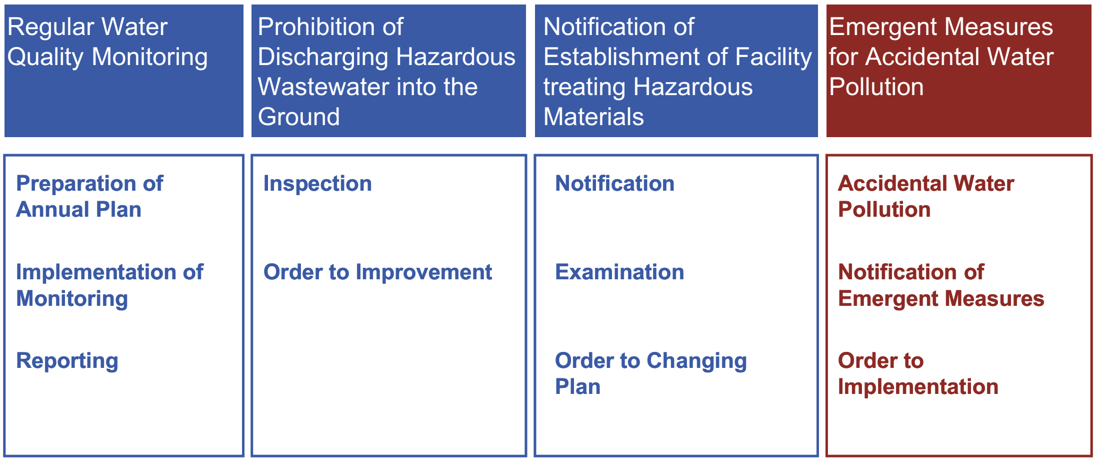

Figure 7. Outline of Groundwater Quality Management in Tokyo
Source: Tokyo Metropolitan Government 1989.

In order to effectively conduct regular groundwater quality monitoring within the limited budget, there are three types of surveys with different purposes, namely (1) Baseline Survey, (2) Survey for Wells surrounding Contamination Point, (3) Periodical Survey (figure 8);

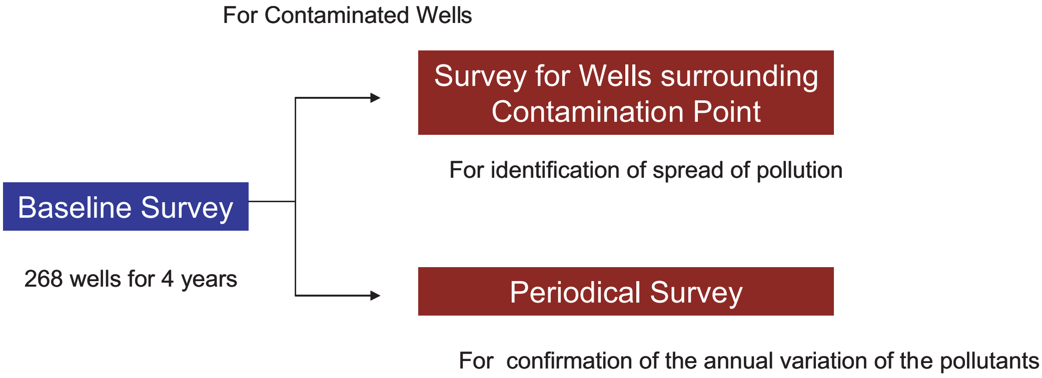

Figure 8. Outline of Groundwater Quality Monitoring in Tokyo
Source: Tokyo Metropolitan Government 1989.

For the first step, Tokyo area is sectioned into 268 blocks with a monitoring well per block. One quarter of the blocks are monitored in a year, with another quarter checked during the next year. All blocks are scanned once within every four years. If groundwater contamination is identified in a well, several wells surrounding the contaminated well are monitored in order to identify the spread of pollution. In addition, that well is then monitored every year to confirm the annual variation of the pollutants.

In terms of the prohibition of discharging hazardous wastewater into the ground, the inspection to the industry under the law is conducted to check the situation of hazardous wastewater discharging. The following table shows the result of the inspection in 1992 and 1998. Although there were several factories which violated the law and were advised to voluntarily improve their wastewater discharging system, so far no factories in Tokyo have been forced by law to make changes to their water systems.

Table 1. The result of Inspection to Industry in Tokyo

Year	Number of Factory for Inspection	Number of Factory committing the Violation
1992	194	7
1998	124	1

Source: Tokyo Metropolitan Government 1989, Tokyo Metropolitan Government 2004.

4. Effectiveness and Limitation of Policy Measures

Groundwater quality management in Tokyo was established to mainly address contamination by VOCs. Reviewing the policy measures from the standpoints of both supplying safe water and sustainable groundwater use, effectiveness and limitations are pointed out in the following;

i. It was not until 1980's that the Japanese Government paid attention to the VOCs contamination of groundwater and started addressing it. However, as shown in the following figure, because VOCs such as trichloroethylene and tetrachloroethylene have been produced and consumed in Japan before 1980's, groundwater was subjected to the risk of VOCs contamination before its problem was actualized.

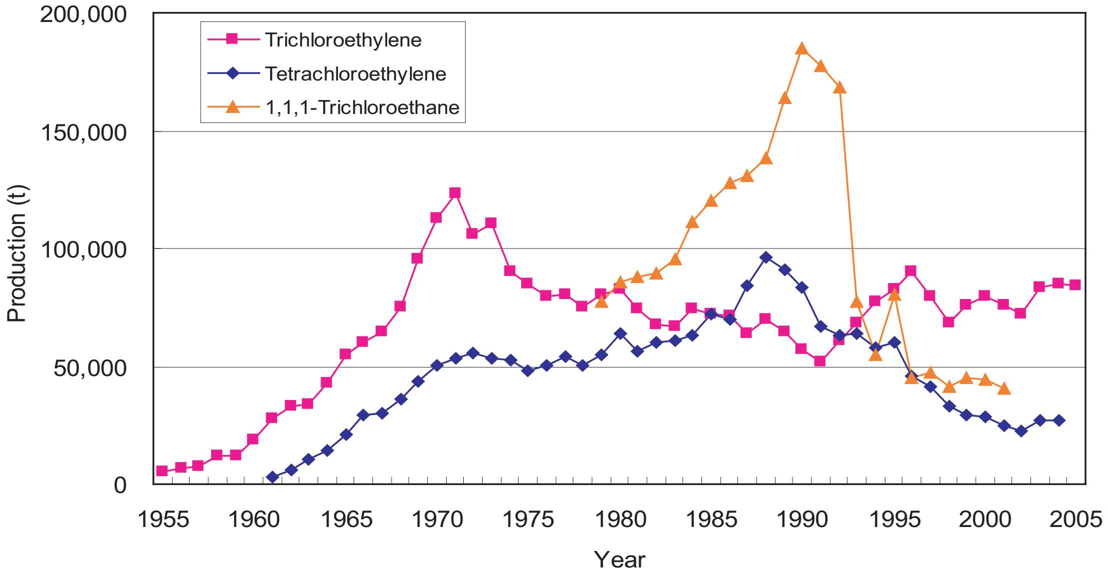

Figure 9. Production of VOCs in Japan (national level of data)
Source: Ministry of Economy, Trade and Industry, 1955-2005

ii. Pollution control of the prevention of VOCs contamination has succeeded to some extent, because newly contaminated wells were identified quickly from the result of the baseline survey.

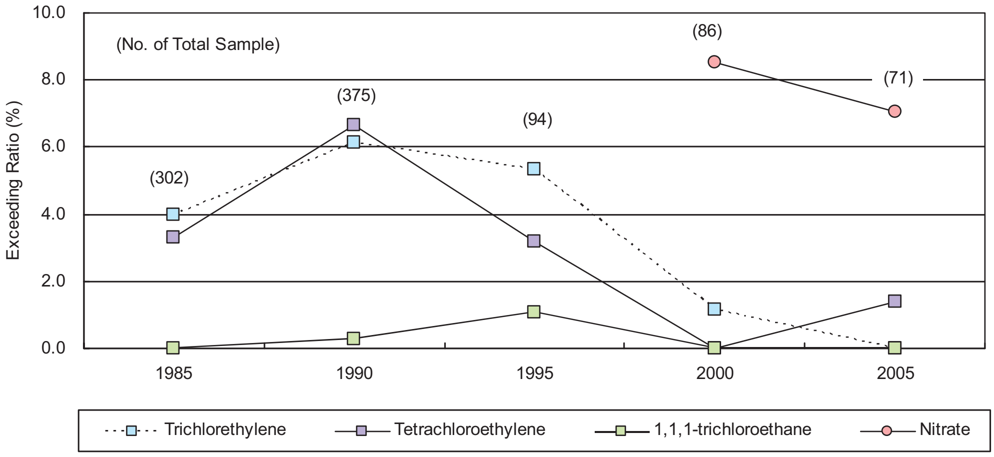

Figure 10. Result of Baseline Survey (VOCs and Nitrate)
Source: Tokyo Metropolitan Government Environment Bureau 1989-2005

iii. However, once groundwater is contaminated by VOCs, it takes a long time for the contaminated groundwater to become improved to a level which is safe and which complies with the standard.

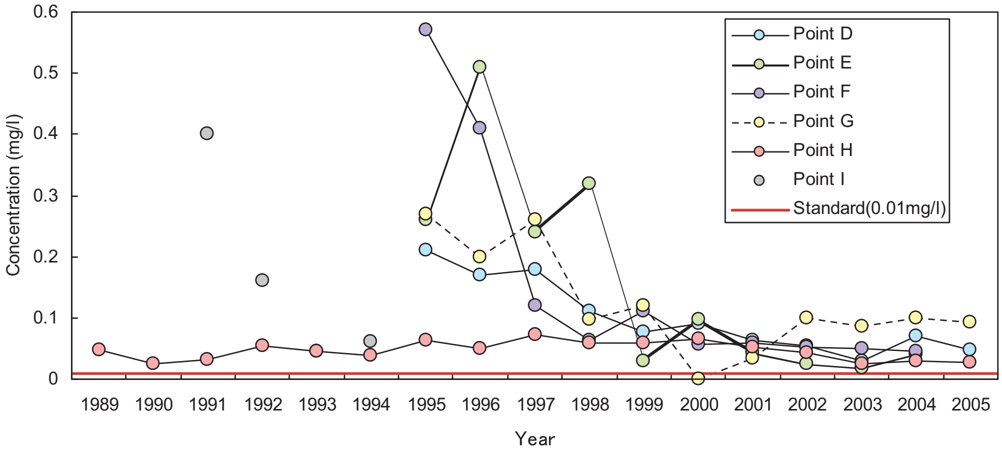

Figure 11. Result of Periodical Survey (above: trichloroethylene, below: Tetrachloroethylene)
Source: Tokyo Metropolitan Government Environment Bureau 1989-2005

iv. The following figure shows the result of periodical monitoring on the annual change of nitrate-nitrogen level of groundwater. The monitoring reveals that most contaminated wells have not been improved for long periods. Unlike VOC contamination, nitrate-nitrogen pollution of groundwater is pointed out to be caused by non-point sources such as chemical fertilizer of agricultural land or night soil of live stock. Because the current pollution control focuses on point source sollution, especially pollutants from the industrial sector, it is not effective in preventing groundwater contamination caused by non-point sources. For improvement of nitrate contamination, pollution control measures for non-point sources should be developed.

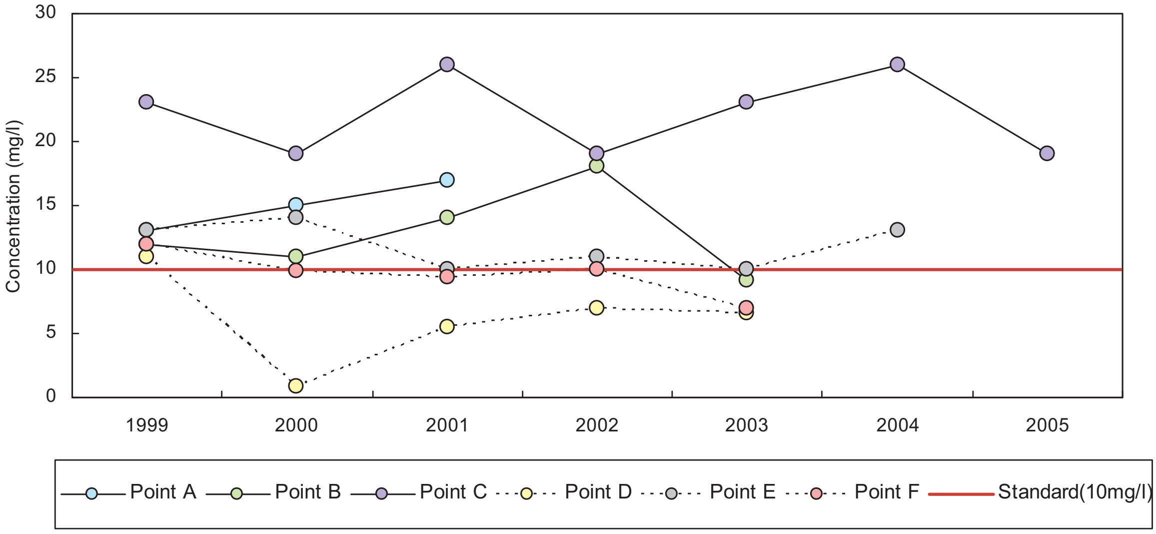

Figure 12. Result of Periodical Survey (Nitrate-Nitrogen)
Source: Tokyo Metropolitan Government Environment Bureau 1999-2005

v. Review and revision of the current water quality standard and monitoring system for drinking water have been conducted several times to address new type of pollutants, such as pesticides, dioxin, endocrine disturbing chemicals, and other hazardous chemicals. For groundwater, the national environmental standard was revised in 1999 to additionally regulate fluoride, boron and nitrate/nitrite-nitrogen. In addition, Tokyo started monitoring groundwater for dioxin in 1998. Because pollutants for groundwater will become continuously diversified, there will come a time when current groundwater quality management measures cannot solve the new types of groundwater pollution. Therefore, the new types of pollutants which can pollute groundwater should be investigated from the aspect of chemical and physical characteristics, and the risk to health, before the impact of the pollution become serious. When the result of the investigation demonstrates a high risk from a pollutant, it should be added to the indicator of quality standard and monitoring.

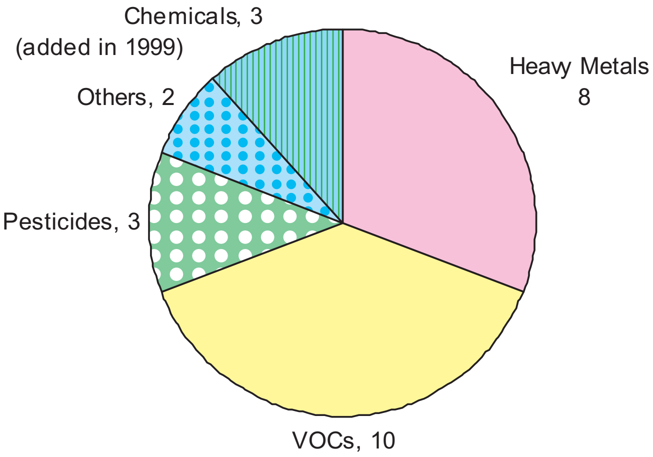

Figure 13. Indicators of Groundwater Quality Standards

vi. In addition to current water use, water use not only for recreation or river purification, but also for emergency purposes are presently being studied in Tokyo. As a pilot project, surplus groundwater under the subway station is transferred to polluted rivers for purification. However, groundwater quality control required for the usability of the water should be conducted proactively.

5. Conclusion

Because contamination of groundwater causes the decrease of available water, it is a quite serious problem related both to issues of quantity and quality. However, in Tokyo, as with most cities in Japan, the establishment of a legal framework for groundwater quality management came later than with other water resources, as groundwater pollution did not become a serious problem until the 1980's. It was not until 1989 that the first law on groundwater quality management (amended "Water Pollution Prevention Law") was formulated.

Although the time period of efforts on groundwater pollution control is not so long, the experience of Tokyo on groundwater quality management provides several lessons for groundwater quality management in Asia.

First, the pollution control measures for groundwater which were provided after groundwater contamination by VOCs was first identified in 1980's have been effective to a certain extent. However, because the measures specialized in prevention of hazardous chemicals leaking into the ground from industry, it could not work for mitigation of contaminated groundwater. In addition, contamination caused by non-point sources such as nitrate-nitrogen was not improved simply by the measures for point source.

Moreover, although Tokyo, the city which completed conventional quality control measures such as water supply and sewerage system, was able to address known pollutants for groundwater, in the 1980's it was quite weak in dealing with unknown contaminants such as VOCs. Because, groundwater is always exposed to increasingly complex pollutants, both continuous implementation of quality monitoring and periodical revision of indicators for groundwater standards monitoring are required. In addition, innovative pollution control measures for new type of pollutants should be developed for enhancing safe groundwater access in the near future.

Considering lessons from Tokyo on groundwater quality management, not only the continuously strengthening of current management measures, but also the creation of innovative pollution control measures for new types of contamination are required in order to promote sustainable and proactive groundwater use for Asia in the future.

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