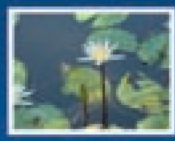

PART II

# THE STATE OF GROUNDWATER RESOURCES AND MANAGEMENT IN CASE STUDY CITIES

## - Summary of Situation Analysis -

This part presents a summary of the situational analysis of the status of groundwater resources, existing policy measures and future challenges for six case study cities, namely Tianjin (China), Bandung (Indonesia), Colombo and Kandy (Sri Lanka), Bangkok (Thailand) and Ho Chi Minh City (Viet Nam). The case of Osaka is also cited as a reference case.

The status of groundwater resources and the policy measures implemented differs from city to city, but the case study cities share some common challenges in groundwater management. In addition, the social, economic, cultural, and environmental circumstances differ in each city. The situational analysis intends to identify such common challenges through the analysis of key elements in groundwater resources management. The analysis provides a basis for the recommendations presented in Part I.

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



## 1. General Background to the Case Study Cities

### 1-1. Socio-Economic Conditions

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

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

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

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

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

## 1-2. Climatic Conditions

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

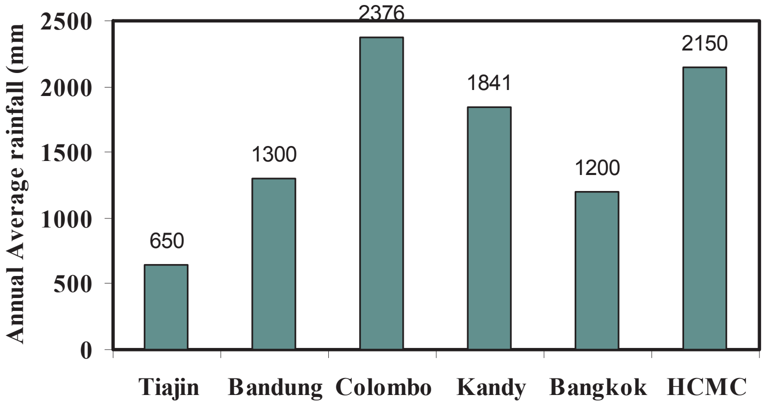


**Figure II-1. Annual Average Precipitation**

**Table II-2. Average Maximum and Minimum Temparature**

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

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

## 1-3. Hydrogeology

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

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

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

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

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

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

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

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

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

## 2. The State of the Groundwater

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

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

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

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

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

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

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

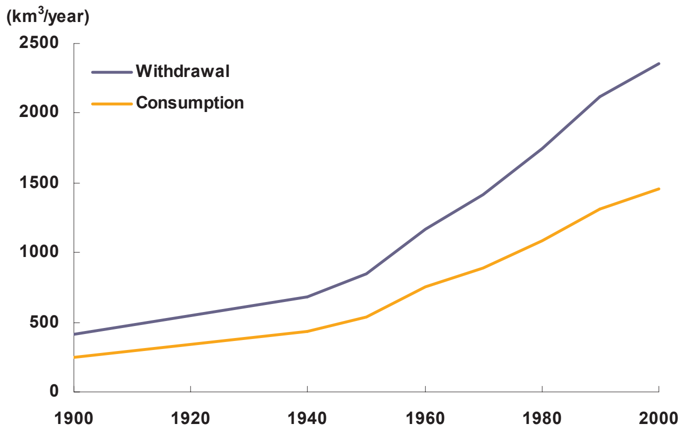


**Figure II-2. Water Extraction and Consumption in Asia between 1950 and 2000**

*Note: The figure in 2000 is projection.*

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

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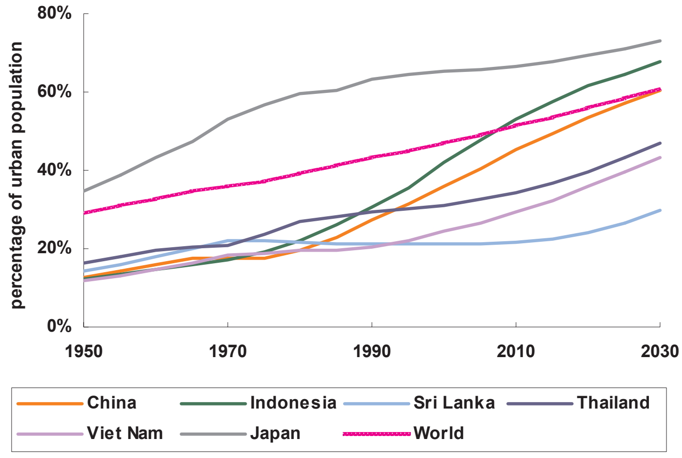



**Figure II-3. Percentage of Urban Population in Selected Countries in Asia**

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

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

## 2-1. Availability of Water Resources and Abstraction

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

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

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

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

## 2-2. Dependency of Groundwater Resources and Beneficial Use

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

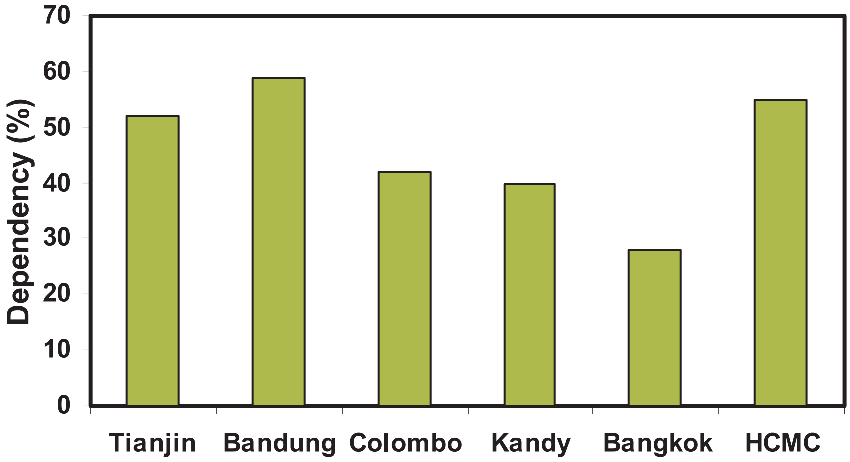



**Figure II-4. Recent Dependency on Groundwater**

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

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

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

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

**Table II-6. Per Capita Water Use**

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

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

## 2-3. Trend of Groundwater Use

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

**Table II-7. Trend of Daily Water Groundwater Use**

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

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

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

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

**Box II-2. General Path of Groundwater Development**

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

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

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

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

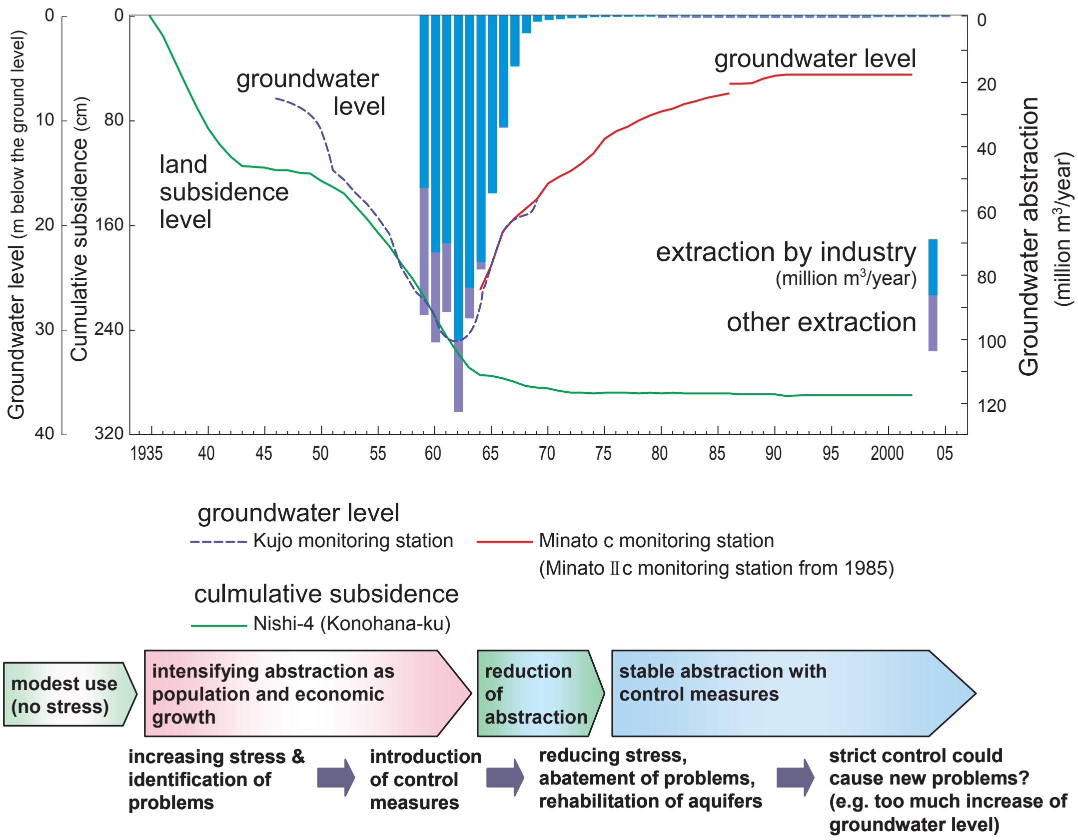



**Figure II-5. General Path of Groundwater Development (Osaka City as an example)**

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

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

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

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

*Note: the values in this table not average but apply to specific locations.*
*(-) Data is not available*

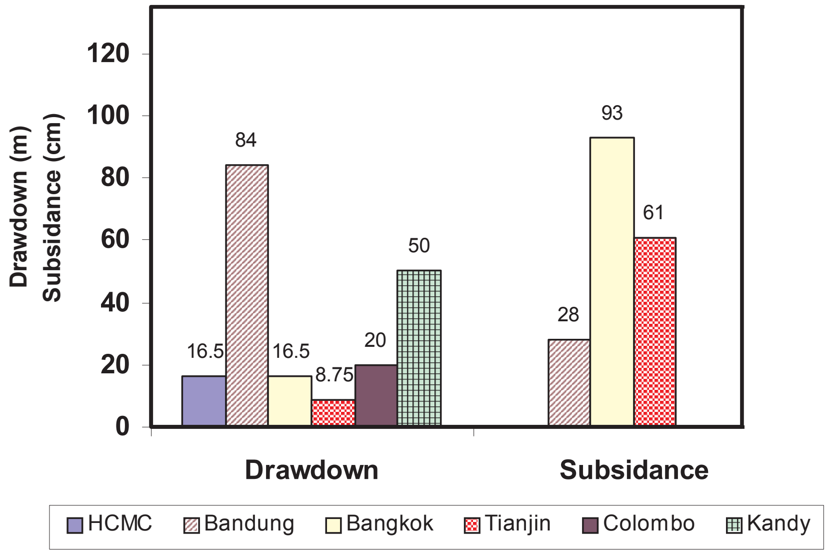



**Figure II-6. Accumulative Drop in the Water Level and Land Subsidence in the Study Area**

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

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

## 2-5. Deterioration of Groundwater Quality

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

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

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

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

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

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

## (1) Naturally occurring pollutants

• **Fluorine**

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

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

## (2) Anthropogenic pollutants

• **Salinity (Chloride)**

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

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

PART II

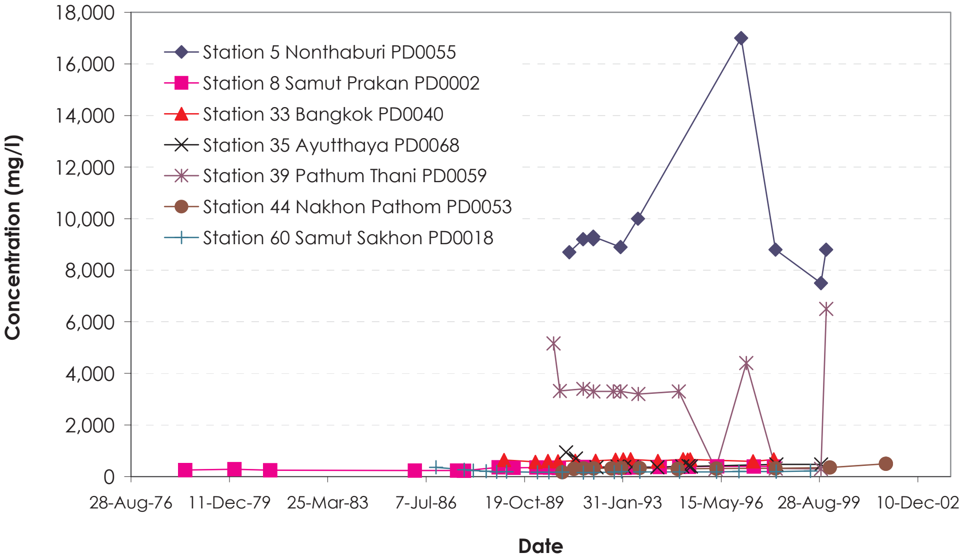



**Figure II-7. Chloride Concentration in Phra Pradaeng Aquifer, Bangkok**

*Source: Department of Mineral Resources, Royal Thai Government*

PART II

• **Nitrates**

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

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

• **Coliform**

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

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

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

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

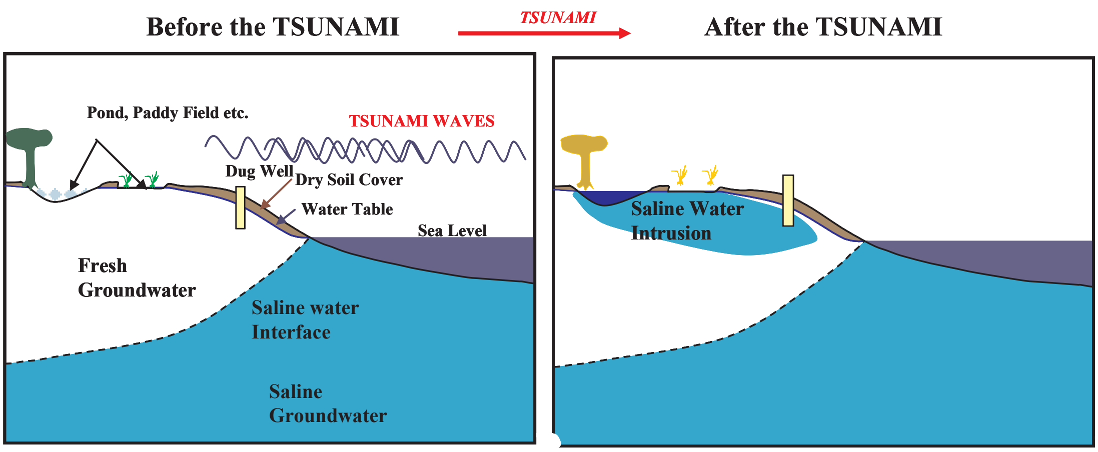
**Million MPN/100 ml*

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

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

### (3) Contamination caused by the tsunami

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




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

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

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

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

## 3-1. Urbanisation

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

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

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

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

**During 2000 to 2003 period*

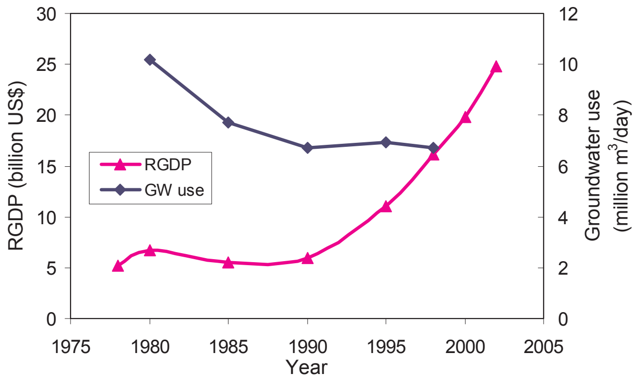
Another key factor influencing the so-called "safe yield" of an aquifer is the degree of recharging capacity available (the "safe yield" of an aquifer in most literature is defined as the amount of water that can be withdrawn from a particular aquifer without producing undesirable consequences). As most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

## 3-2. Economic Growth and Groundwater Abstraction

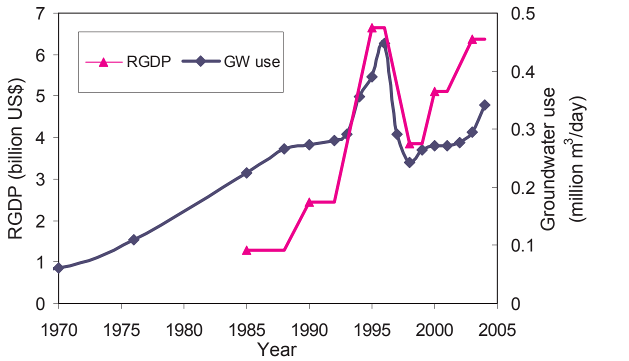
Figure II-9 shows that there is a strong correlation between historical groundwater use and economic growth (in terms of study area RGDP and industry RGDP) in Bandung and HCMC. On the other hand, in the case of Tianjin, the trend is the reverse where groundwater use declined with increased RGDP. Bangkok's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

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

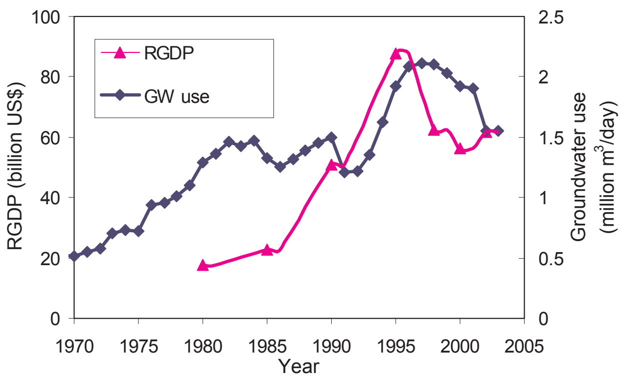
Most of the RGDP in the case study cities is from industrial activity, signifying that the two are in directly proportion. Therefore, groundwater use in the industrial sector is the key to future groundwater demand, particularly in cities where the dependency on groundwater resources in the industrial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



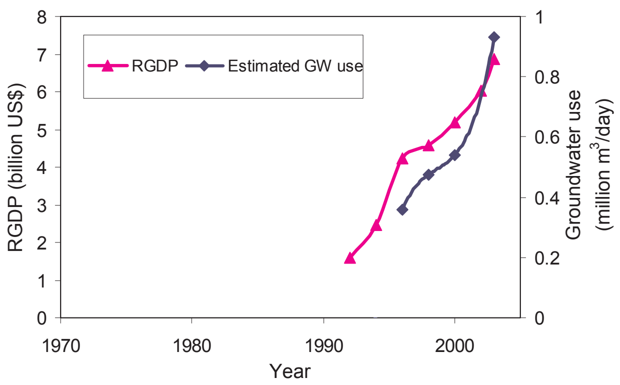

**(a) Tianjin**




**(b) Bandung**




**(c) Bangkok**




**(d) HCMC**

**Figure II-9. Historical Groundwater Use and Economic Development**

## 3-3. Water Supply and Sanitation

### (1) Piped water coverage

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

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

(unit: %)

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

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

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

## (2) Sanitation

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

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

Tianjin

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

Bandung

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

Colombo

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

Kandy

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

Bangkok

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

Administration, with a potential total capacity of one million cubic meters per day of wastewater treatment by 2000. By 2005, seven treatment plans have finished construction, and five treatment plants located within Bangkok city are in operation, with the coverage ratio by population being about 26 % in the city
- All private properties are required to have some form of wastewater treatment facility. Houses that are not connected to the central sewer systems must at the least install septic tanks for sanitation.
- Wastewater from such activities as bathing and washing are allowed to go directly into the drains without pre-treatment.

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

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

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

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

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

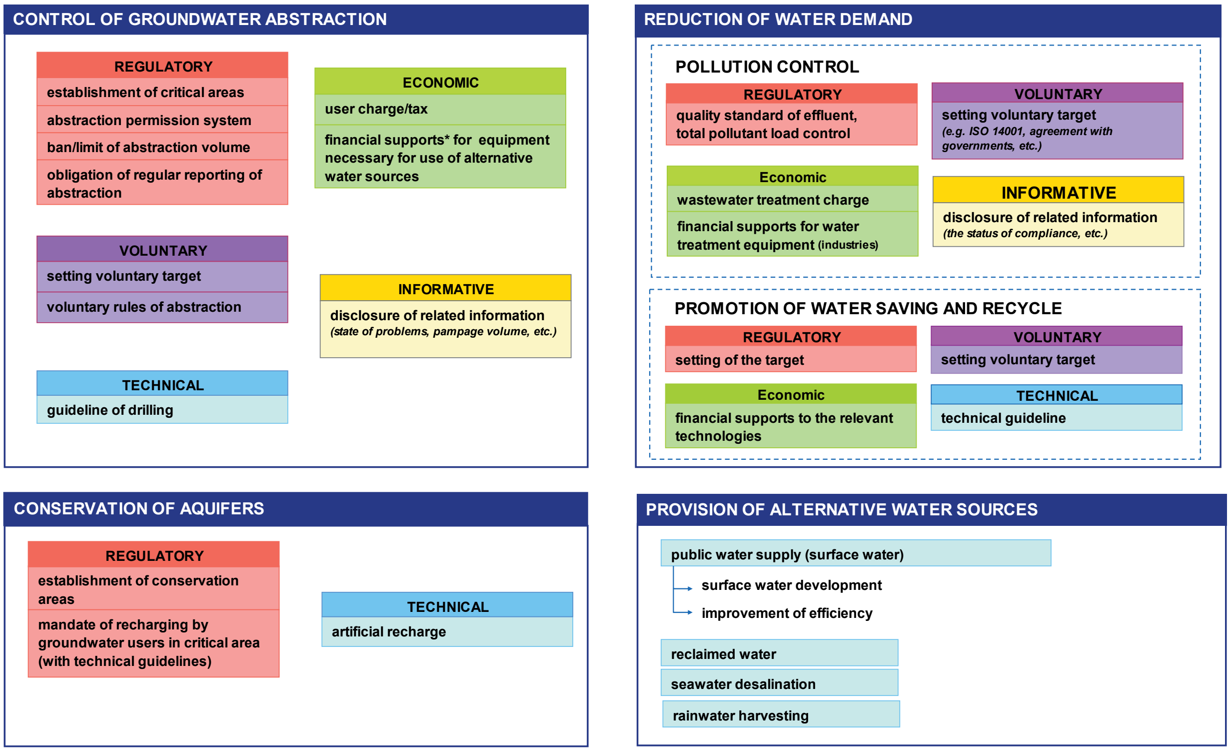



**Figure II-10. Areas and Measures of Groundwater Management (quantity control)**

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

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

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

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

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

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

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

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

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

Table II - 13. Continued

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

*Note: a. The information in this table was based on the case study report of respective cities.*
*b. Information of Colombo and Kandy was not referred in this table because there are no specific policy responses in these cities.*
*c. In Thailand, at present no specific legal instrument exists in any law that clearly establishes the ownership on water of that specifies to whom water belongs. Nonetheless, in accordance with generally accepted principles of law and special legal provisions in various acts the ownership of all water resources is vested in the State. (JICA et al., 1999)*
*d. In Japan, there are no provisions regarding rights regarding groundwater, but it is regarded that the land owners have an exclusive right of groundwater use.*

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

### (a)Tainjin

***Measures taken***

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

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

- **Restriction of groundwater abstraction**
  "Temporary Measures for Groundwater Management in Tianjin" were introduced in 1987 to control groundwater abstraction in the city. Under the

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

• **Groundwater charge*[1]**

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

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

**Table II-14. Groundwater Charge in Tianjin**

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

**BoxII-3. Water Rationalization in Tianjin**

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

### *Effectiveness of the Control Measures*

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

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

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

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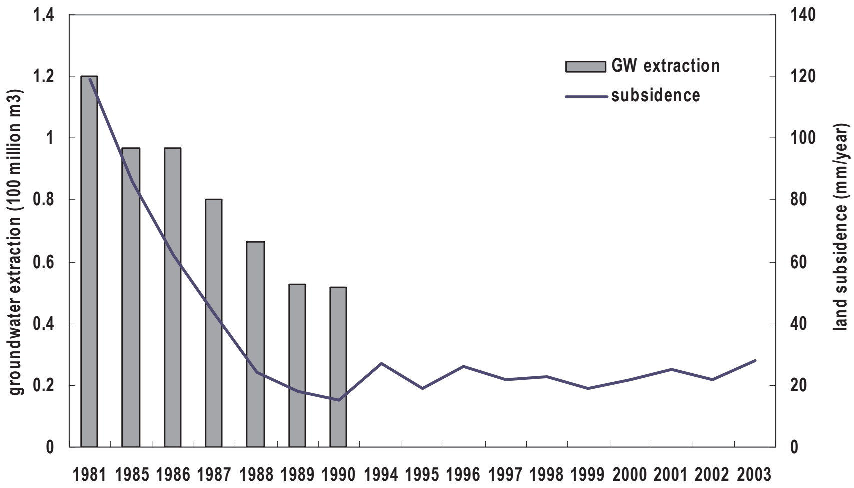


**Figure II-11. Groundwater Abstraction and Subsidence in the Urban District of Tianjin**

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

## (b) Bandung

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

*Measures taken*

- **Regulation of groundwater abstraction**

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

- **Groundwater Use Tax*[2]**

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

**Box II-4. Impact of Decentralization and Groundwater Management**

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

### *Effectiveness of the Control Measures*

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

*2. 1 Indonesian Rupiah = 0.000109 USD (as of 7 March 2006)

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

### (c) Bangkok

*Measures taken*

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

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

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

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

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

*Effectiveness of the Control Measures*

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

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

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

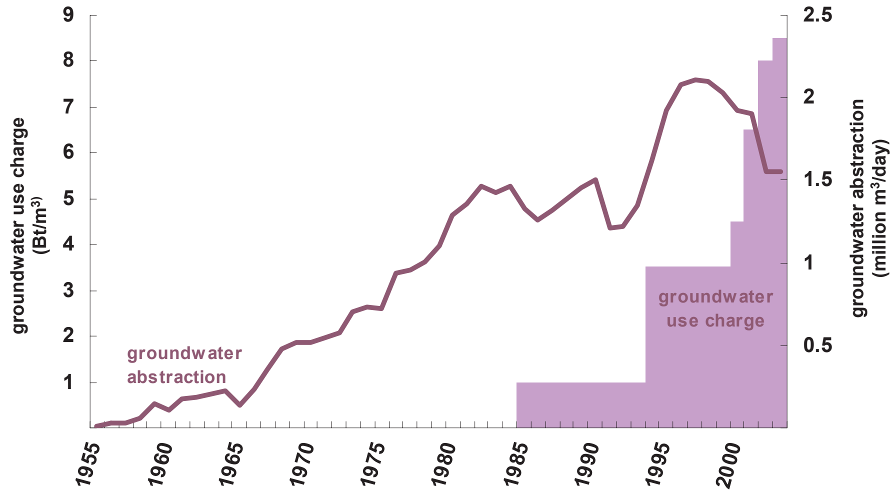


**Figure II-12. Groundwater Abstraction Volume and Charges for Use in Bangkok**

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

## (3) Implementation Barriers and Challenges Identified

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

**(a) Deficiency of the existing measures**

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

**(b) Institutional problems**

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

**(c) Others**

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

## (4) Lessons from Groundwater Management in Osaka

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

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

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

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

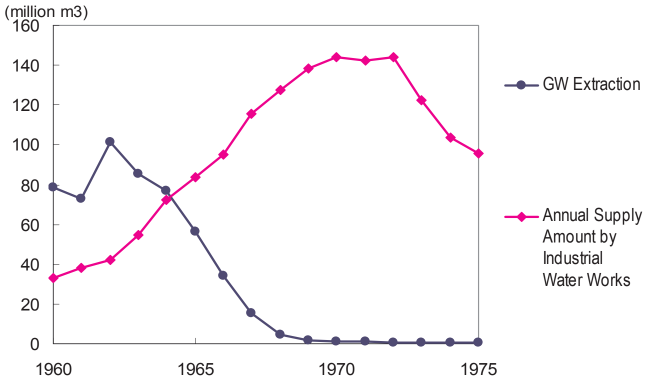


**Figure II-13. Transfer of Groundwater Use to Industrial Water Supply Works in Osaka**

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

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

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

### *Long-term impacts of the policy measures*

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

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

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

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

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

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

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

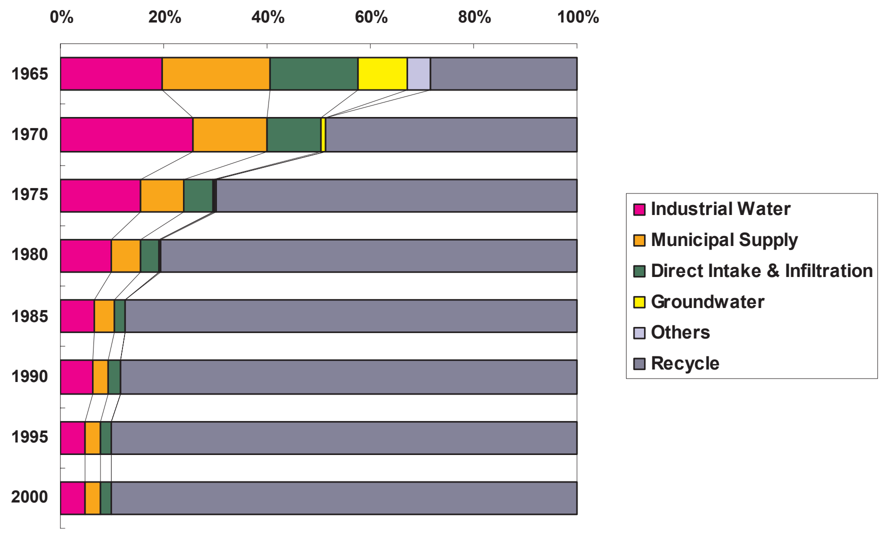


**Figure II-14. Freshwater Supply for the Industrial Sector, by Source (Osaka City)**

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

### *Lessons*

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

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

## (5) Challenges of Groundwater Management in Asian Cities

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

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

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

## 4-2. Groundwater Management (quality-wise)

### (1) Current Status

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

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

### (2) Measures and technologies for coping with aquifer contamination

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

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

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

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

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

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

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

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

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

## (3) Challenge and Future Prospects

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

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

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