

Chapter 1

What are the Subsurface Environmental Problems?

Groundwater and Subsurface Environmental Assessments Under the Pressures of Climate Variability and Human Activities in Asia

Makoto Taniguchi

Abstract Subsurface environmental problems, such as land subsidence, groundwater contamination, and subsurface thermal anomalies, are important aspects of human life in the present and future but have not been evaluated as yet. Interactions between surface/subsurface and subsurface/coastal environments under the pressures of climate variability and human activities have been analysed for the cities of Tokyo, Osaka, Bangkok, Manila, Jakarta, Taipei, and Seoul, which are in different stages of urbanization. Analyses from satellite GRACE data showed that land water storage in Bangkok decreased since 2002. Groundwater tracers and 3D numerical simulations of groundwater showed that the groundwater flow system in the urban aquifer has been highly disturbed by pumping, causing a vertical downward flux in the urban area. Subsurface temperatures observed in the study cities illustrate the magnitude and timing of surface warming due to global warming and heat island effects. The amount of the increase in surface temperature was found to be larger in the city center than that in suburban and rural areas, reflecting the degree of urbanization. Contamination histories in each city have been reconstructed from sediment studies of nutrient and heavy metal contaminations. Analyses of land cover/use changes show that urbanization caused a reduction of groundwater recharge and an increase in thermal transfer into the subsurface environment. Two groups of integrated indicators: (1) natural capacities; and (2) changing society and environments, were used to analyse the relationships between the developmental stage of the city and the subsurface environment. Comparing Tokyo with each city shows that some cities have a benefit by developing later and/or benefit from a natural capacity such as higher groundwater recharge rate as higher input to aquifer. However, excessive development in Jakarta causes severe damage by land subsidence. Groundwater and subsurface environments should be investigated for their adaptation and resilience to changing environment conditions. In addition,

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subsurface environments should be treated together with surface and coastal environments for better management and sustainable use.

1.1 Introduction

Climate variability and increased demand for groundwater as a water resource due to increasing population has resulted in many subsurface environmental problems including land subsidence, groundwater contamination and subsurface thermal anomalies. These problems have occurred repeatedly in Asian major cities with a time lag depending on the developmental stage of urbanization (Taniguchi et al. 2009a). Thus, one may be able to assess future scenarios if we can evaluate the relationships between subsurface environmental problems and the development stage of the city. Although surface waters are relatively easy to evaluate, the changes in groundwater and other parts of the subsurface environment remains a difficult task.

While global warming is considered as a serious environmental issue above the ground or near the ground surface, subsurface temperatures are also affected by surface warming (Huang et al. 2000). In addition to global warming, the “heat island effect” due to urbanization creates subsurface thermal anomalies in many cities (Taniguchi and Uemura 2005; Taniguchi et al. 2007; Taniguchi et al. 2009b). The effect of heat islands on subsurface temperature is a global environmental issue because increased subsurface temperature alters soil water and groundwater systems chemically and microbiologically through geochemical and geobiological reactions that are temperature sensitive (Knorr et al. 2005).

Water and thermal energy are separated at the earth surface into the atmosphere and geosphere (subsurface) depending on land cover and use. Therefore analysis of changes in land cover/use can indicate the factors controlling subsurface environments. For instance, the change in land cover/use from open fields to houses and other structures results in decreases in groundwater recharge due to an increase in impermeable layers at the surface. This change also causes the increase in thermal energy into subsurface environment due to the change in heat balance at the earth’s surface.

This study was intended to assess the effects of human activities on the urban subsurface environment, an important aspect of human life in the present and future but not yet evaluated. This is especially true in Asian coastal cities, where population numbers/densities and water demand have increased rapidly and uses of the subsurface environment have increased. The primary goal of this study was to evaluate the relationships between the developmental stage of cities and various subsurface environmental problems, including extreme subsidence, groundwater contamination, and subsurface thermal anomalies. We address here the question of sustainable use of groundwater and subsurface environments to provide for better future development and human well-being.

The subjects (Fig. 1.1) and research methods used in this investigation are as follows: (1) Urbanization; relationships between the developmental stages of cities and subsurface environmental problems were assessed by socio-economical analyses

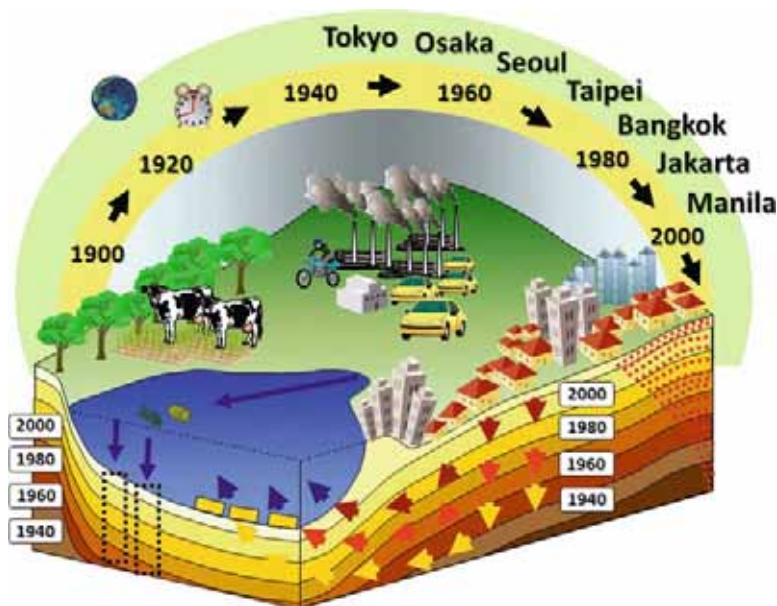


Fig. 1.1 Schematic diagram of the study theme

and reconstructions of urban areas based on GIS using historical records; (2) Groundwater; serious problems in subsurface environments and changes in reliable water resources were studied after evaluations of groundwater flow systems and changes in groundwater storage by use of hydrogeochemical data and in-situ/satellite-GRACE gravity data; (3) Material; accumulation of materials (contaminants) in the subsurface and their transport from land to ocean including groundwater pathways were evaluated by various techniques; and (4) Subsurface temperature; subsurface thermal contamination due to the “heat island” effect in urban areas was evaluated by reconstruction of surface temperature history and urban meteorological analyses.

1.2 Study Area and Methods

In order to assess the groundwater resources under the pressures of climate variation and human activities in Asia, intensive field observations on subsurface environments and data collections have been made in the urban basins including Tokyo, Osaka, Bangkok, Jakarta, Manila, Seoul, and Taipei (Taniguchi et al. 2009a, b, Fig. 1.2), where are mostly capitals and/or mega cities.

Subsurface temperatures have been measured in boreholes with one meter depth resolution to evaluate the climate change and heat island effects (Taniguchi and Uemura 2005; Taniguchi et al. 2007; Yamano et al. 2009). Temperatures were measured in 29 boreholes in Tokyo, 37 boreholes in Osaka, 15 boreholes in Seoul, and

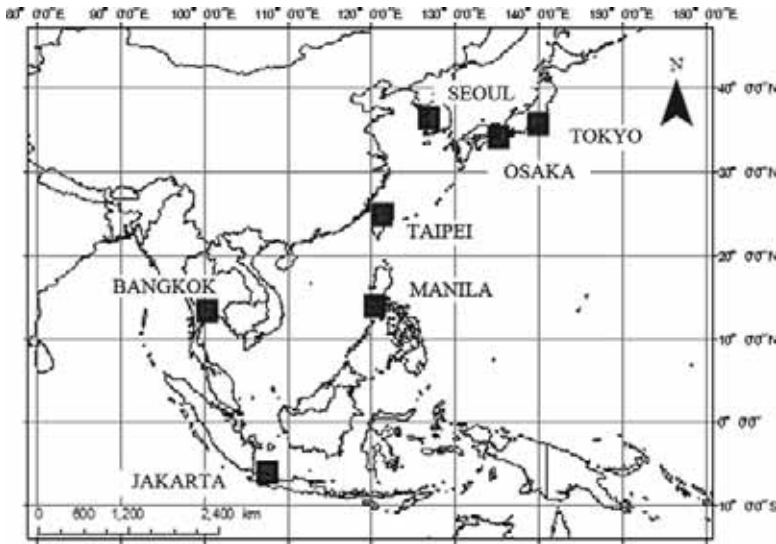


Fig. 1.2 Location of the study areas

14 boreholes in Bangkok. Thermistor thermometers, which can read temperature at a 0.01°C precision and an accuracy of 0.05°C , were used in these measurements. The diameter and depth of the boreholes in Tokyo are 8–20 cm (mostly 15 cm) and 126–450 m (mostly 200–300 m), respectively. Well diameters in Osaka are 10–40 cm (mostly 20 cm) and the depths range from 47 to 465 m (mostly 60–200 m). The depths of the boreholes in Bangkok and Seoul are 55–437 m and 498–968 m, respectively. The diameter of these boreholes is mostly around 10–30 cm. Therefore, no thermal free convection is expected (Taniguchi et al. 1999). The geology and other information concerning the aquifers in each city are given in Taniguchi et al. (2007).

One of the tools for evaluating the change in global/regional land water storage (LWS) is the use of satellite GRACE (Gravity Recovery And Climate Experiment) which was launched at 2002. Although GRACE is providing extremely high precision gravity field data from space, its spatial resolution is not enough to reveal the urban scale variations. However, recent study shows the GRACE data can be used for the study of water budget on a basin scale (Yamamoto et al. 2009).

To analyze the change of groundwater flow caused by the over-pumping in urban areas, a 3D numerical model with MODFLOW have been established in the area of Tokyo, Osaka, Bangkok, and Jakarta with the help of long term observation data of groundwater potential distribution. In addition to this, groundwater age tracers including CFCs and C-14 have been used to extract the time-series chemical records stored in the aquifer that has affected by the urban over-pumping resulting in accelerated groundwater flow.

Material contaminations in each aquifer are evaluated from the point of view of nutrient and heavy metal contaminations. Groundwater samplings in each city have been made for analyses of chemical components and stable isotope ratios, including N, C and Sr, to reveal the source of the contamination. Sediment cores near each

city coast were sampled, and analyzed to reconstruct the contamination history back to approximately 1900.

In order to evaluate the surface environment which distributes water, heat, and materials into the subsurface, land use and cover conditions at three different periods (1930s, 1970s and 2000s) have been analyzed using GIS with a 0.5 km grid for each targeted cities. Land cover/uses were categorized into the following nine types: forest, house, industries, paddy field, other agriculture field, grass/waste land, ocean, water and wet land, and others.

To integrate all information concerning possible relationships between developmental stage of the city and subsurface environmental problems, we examined three subsurface environmental problems: land subsidence, groundwater contamination, and subsurface thermal anomalies. For each subsurface environmental problem, two sets of integrated indicators are used for the analysis. The first indicator is termed “natural capacities”, that includes such characteristics as groundwater recharge rate and groundwater storage. The second indicator is referred to as “changing society and environment” and this includes population, income, industrial structure, groundwater dependency, groundwater pumping rate, groundwater level, and land subsidence.

1.3 Degradation of Groundwater Resources Due to Climate Variation and Human Activities

At the early stage of the urbanization, groundwater demand for industrial and domestic uses in the city increases because the groundwater is relatively inexpensive, has easy access, and provides stable and clean water resources. After increased groundwater consumption, the groundwater level decreases, and various subsurface environmental problems begin to occur such as land subsidence, groundwater salinization, dissolved oxygen reductions, and others. Thus, a shift in reliable water resources from groundwater to the surface water has occurred in many Asian cities (Fig. 1.3), due to an increase in demand of water resources (Taniguchi et al. 2009a). One of the reasons why these shifts occurred was due to severe land subsidence caused by excessive groundwater pumping in coastal Asian cities. Since the aquifers in these cities consist mainly of sedimentary formations, they are prone to subsidence. For example, the land subsidence in the Osaka plane has been observed since the 1930s due to excessive groundwater pumping for industrial use. The local government finally regulated this pumping after the 1960s. In the case of Bangkok, land subsidence was observed in the 1970s, but the government did not regulate pumping until the late 1990s.

On the other hand, climate change, such as changes in precipitation patterns due to global warming, have resulted in some Asian cities shifting their water resources in the opposite direction, i.e., from surface water to groundwater. For example, Taiwan is now using more groundwater because of the decrease in reliability of their surface water resources stored behind dams. In Taiwan, the decrease in number of precipitation days likely caused by global warming without changing the total amount of precipitation caused a decrease of reliability in their surface water

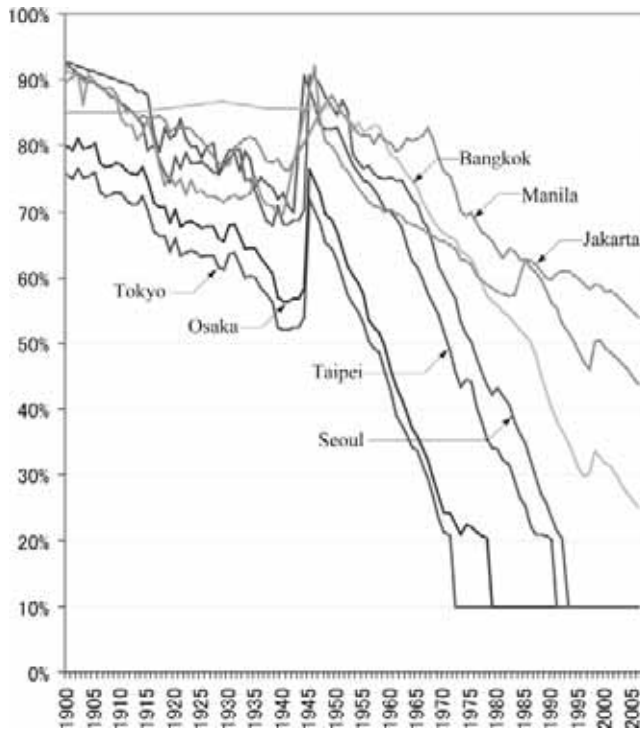


Fig. 1.3 Changes in groundwater dependency in Asian seven cities (modified from Taniguchi 2010)

resources. Therefore, at least in this case, climate change may be a principal reason for changing reliable water resources between surface water and groundwater.

To evaluate the regional groundwater resources, we analyzed updated GRACE data, not only for seasonal variations but also a secular trend of the mass variations in the Chao Phraya river basin (Bangkok). The result showed that the total mass change after 2002 was decreasing downstream of Chao Phraya and increasing upstream (Fig. 1.4). Although the GRACE trend agrees well with the global Terrestrial Water Storage (TWS) model (Fig. 1.4), there are some inconsistencies with regional or local land water models.

Groundwater tracers (CFCs and C-14) used in this study showed that the groundwater flow system in the urban aquifer has highly disturbed by the human pumping. A dominant vertical downward flux was revealed in the urban area by the CFCs and C-14, which originated from human activity in the urban area. Repeated measurement of C-14 of the groundwater in Jakarta show that the younger groundwater in shallower aquifer was directed downward due to groundwater pumping in urban area, making deeper groundwater younger (Fig. 1.5, Kagabu et al. 2010).

A 3D groundwater simulation (MODFLOW) showed a spatial change of the groundwater recharge area for Jakarta which was major recharge area of the pumped aquifer (Kagabu et al. 2010). This spatial change of the groundwater potential was

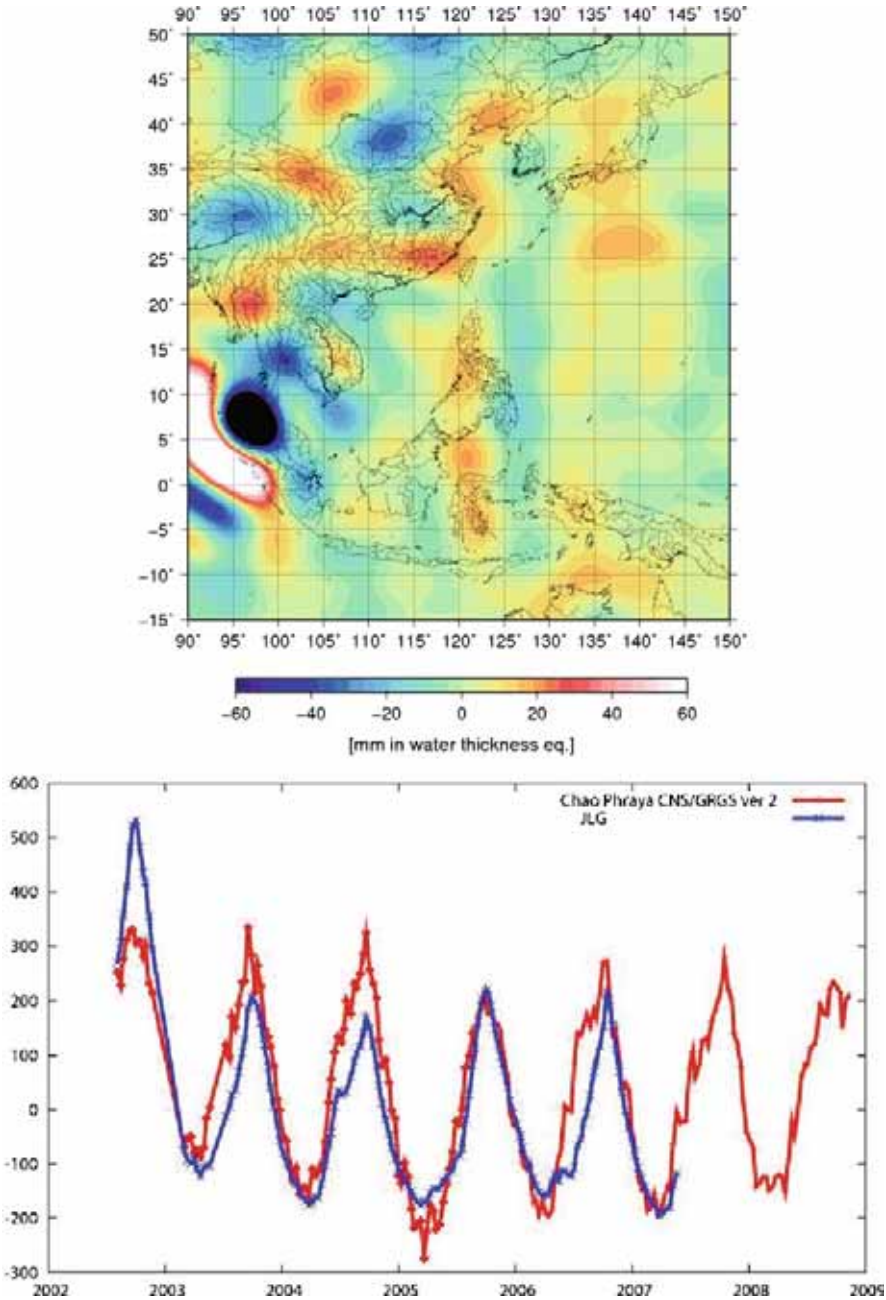


Fig. 1.4 Land water storage change by GRACE and comparison with TWS model (Yamamoto et al. 2009)

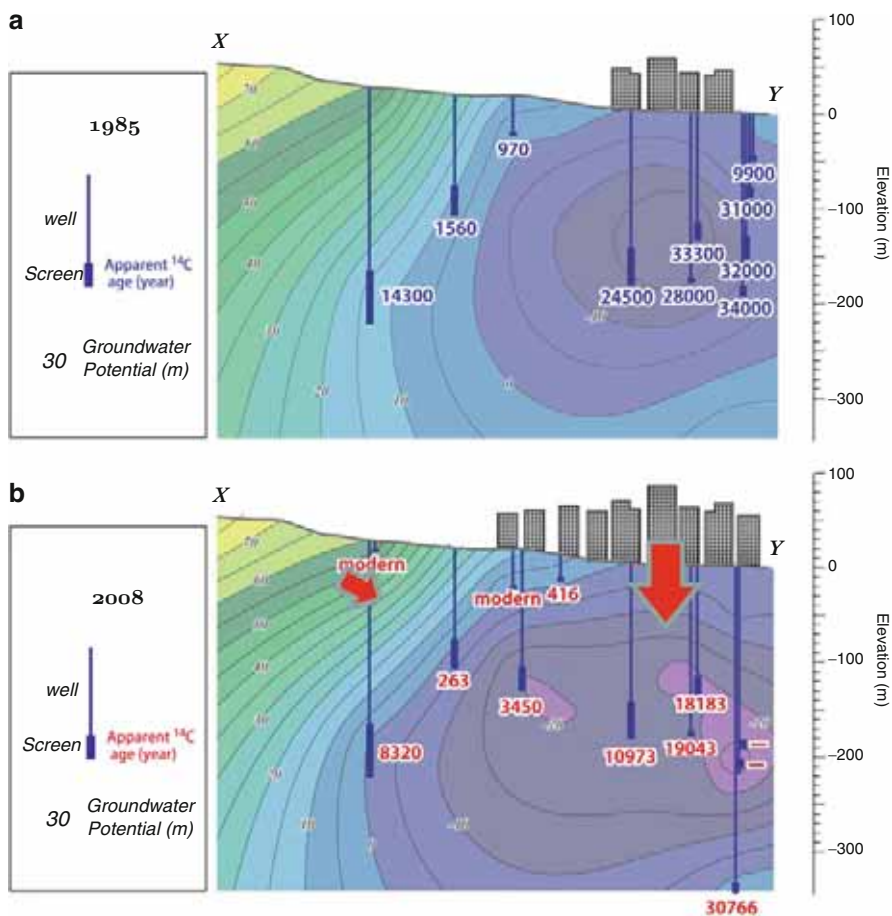


Fig. 1.5 Groundwater age obtained from carbon 14 at 1985 (a) and 2008 (b) (Kagabu et al. 2010)

strongly affected by the regional groundwater pumping regulations, and the success or failure of those regulations are mostly affected by the availability of alternative water resources for the city and the legal aspect of the groundwater resources for each nation.

1.4 Subsurface Thermal Anomalies Due to Surface Warming

Subsurface temperature is affected not only by global warming (Huang et al. 2000) but also by the heat island effect due to urbanization (Taniguchi and Uemura 2005). The combined effects of these two processes can have consequences on the groundwater system. Subsurface temperatures in four Asian cities (Tokyo, Osaka, Bangkok

and Seoul) have been compared to evaluate the effects of surface warming due to urbanization and global warming, and the relationship to the developmental stage of each city (Taniguchi et al. 2007). Mean surface warming in each city ranged from 1.8°C to 2.8°C which was confirmed by air temperature monitoring over the last 100 years (Fig. 1.3). The depth of departure from the regional geothermal gradient was found to be deepest in Tokyo (140 m), followed by Osaka (80 m), Seoul (50 m), and Bangkok (50 m).

The increases in subsurface thermal storage in each city are shown in Fig. 1.6. As can be seen from these plots, the change in subsurface thermal storage was greatest in Tokyo, followed by Osaka, Seoul, and Bangkok. Numerical analyses using a one-dimensional heat conduction theory (Taniguchi et al. 2007) with different magnitudes and timings of the initiation of surface warming showed that the subsurface thermal storage was greater when the magnitude of surface warming was higher, and when the elapsed time from the start of surface warming due to urbanization was longer (Fig. 1.6). This trend was confirmed by air temperature records from each study area during the last 100 years (Taniguchi et al. 2007).

The heat island effect due to urbanization on subsurface temperatures is an important global groundwater quality issue, because it may alter groundwater systems geochemically and microbiologically (Knorr et al. 2005). Many cities in the world have this problem, particularly in Asia, where population has been increasing rapidly. Reconstructions of the surface warming history by use of

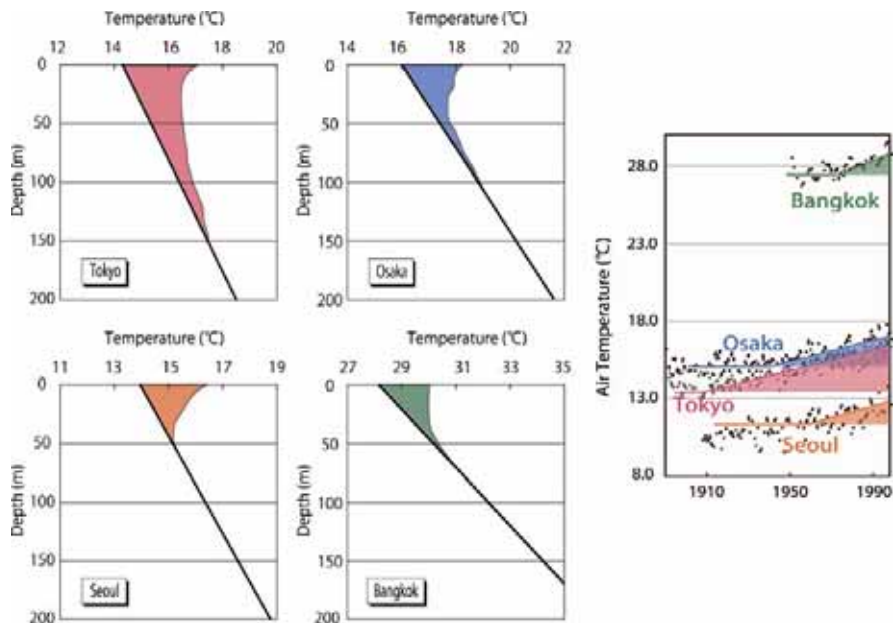


Fig. 1.6 Changes in air temperature and subsurface temperature in Bangkok, Seoul, Tokyo, and Osaka over the last 100 years

subsurface temperatures have been made in rural, suburban, and urban areas of Bangkok (Yamano et al. 2009). The results show that the surface warming started earlier in the current urban area, followed by current suburban area, and then the rural area. Therefore, a record of the expansion of the city can be preserved in these heat island records.

Subsurface heat storage, the amount of heat accumulated under the ground as a result of surface warming, is a useful indicator of the subsurface thermal environment and we can compare its values at specific times with those of other parameters representing urban subsurface environment obtained through various approaches.

1.5 Material Contamination

Nutrient and heavy metal contamination in each aquifer were analyzed and evaluated. Compositions of nitrogen contamination of the groundwater in each city show the nitrate contamination dominated in Jakarta, on the other hand ammonium contamination is dominant in Bangkok (Fig. 1.7, Umezawa et al. 2009).

Stable isotope ratios of N and C of groundwater can be used to indicate the origin of the contamination in Manila, Bangkok, and Jakarta (Umezawa et al. 2009) such as domestic or farm origin, and denitrification processes in Bangkok (Umezawa et al. 2009). Nitrite contamination was found in Jakarta and Manila, on the other hand, denitrification was found to occur in Bangkok even though huge loads of nitrogen. This is attributed to the natural conditions whether oxic or anoxic depending on the land slope (geomorphology), geology (volcanic or sediment), and hydroclimate condition (Hosono 2010).

The sediment cores from near the coast of the city were sampled and analyzed to reconstruct the contamination history back to approximately 1900 (Hosono 2010). Organic pollution and metal pollution histories were reconstructed in Asian cities, showing the changes in the C/N ratios and lead pollution depending on the development stage of the city. Some of the controlling factors included magnitude of loads, regulation of the loads, and others.

Groundwater salinizations were also found in Osaka, Bangkok and Jakarta. The difference of marine alluvium volume (same as topographic gradient), natural recharge and intensive pumping period controlled the degree of salinization. On the other hand, less terrestrial submarine groundwater discharge (SGD) but huge material flux by total SGD was found in Asian coastal cities (Burnett et al. 2007). Spatial variation in SGD was estimated around each city, using topographic models and Rn measurements.

Based on the accumulation and transport of pollutants, we evaluated the “vulnerability risk” in all cities. For example, relatively higher risks of nitrate are found in Jakarta and Manila, and arsenic pollutions were found in other cities, depending upon the redox state (Hosono 2010). The pollution accumulation and transport were controlled by natural factors such as topography, climate and geology as well as human impacts such as pumping rate and pollution load.

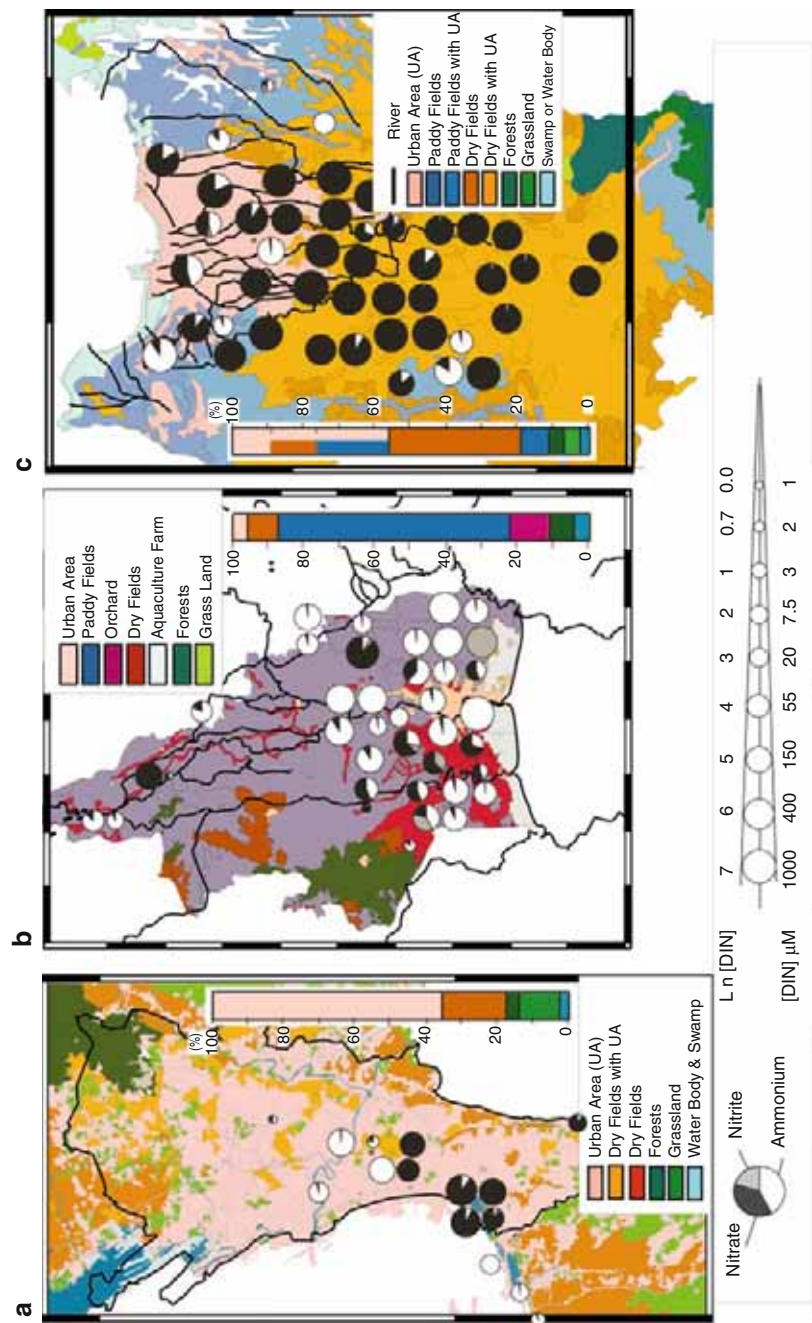


Fig. 1.7 Nitrogen contamination of groundwater in Bangkok (a), Jakarta (b), and Manila (c) (Umezawa et al. 2009)

1.6 Land Cover/Use Analysis for Subsurface Environments

The results of expanding urban areas in seven Asian cities, including Tokyo, Osaka, Seoul and Bangkok are shown in Fig. 1.8 and Table 1.1. As can be seen from these data, the urbanized areas expanded in Tokyo from 1930 to 1970 by 753 km², from 1970 to 2000 by 2,865 km², in Osaka from 1930 to 1970 by 569 km², from 1970 to 2000 by 907 km², and in Seoul from 1930 to 1970 by 196 km², from 1970 to 2000 by 954 km², respectively. Generally, the extension of urban areas decreases the permeable layers, thus reducing the groundwater recharge rate. The extension of urbanized regions also results in an increase of the thermal index which illustrates the magnitude of the heat island effect.

The analysis of land cover/use changes (urbanized area) shown in Table 1.1 indicates that the magnitude of area changed was larger during the period from 1970 to 2000 than during 1930 to 1970. Therefore, urbanization is accelerated more from 1970 to 2000 than from 1930 to 1970. The magnitude of the change in area is also greater in Seoul than in Osaka from 1970 to 2000.

The reliability of groundwater as a water resource may be decreased after urbanization due to reduction of the groundwater recharge rate, and increase of groundwater contamination including subsurface thermal anomalies. However, a new subsurface environmental problem has now occurred in Tokyo and Osaka, the “floating subway station” due to buoyancy by recovering groundwater levels after regulation of the pumping. This is attributed to the enough groundwater recharge to be recovered in the cities which are located in Monsoon Asia. Therefore, the development of integrated indicators are necessary for better understanding the relationship between human activities and the subsurface environment, and proper management.

1.7 Integrated Indicators

We developed two groups of integrated indicators to analyse the relationships between development stage of cities and subsurface environment: (1) changing society and environments, and (2) natural capacities. To analyze the relationships between development stage of the city (indicators of changing society and environment) and subsurface environmental problems, the DPSIR (Driving force, Pressure, State, Impact and Response) model is used for the seven targeted cities. The relationships between social economic stage such as population, and income, and subsurface environmental problems such as land subsidence, contamination and thermal anomalies, were framed for the analyses.

According to the degree of urbanization based on population, economy, groundwater dependency, subsurface problems such as land subsidence, and regulation/law, five development stages were categorized. The first stage is the early urbanization with higher groundwater dependency (more than 50 %), and the second stage is represented by increased water demand due to heavy industries. The third stage is the

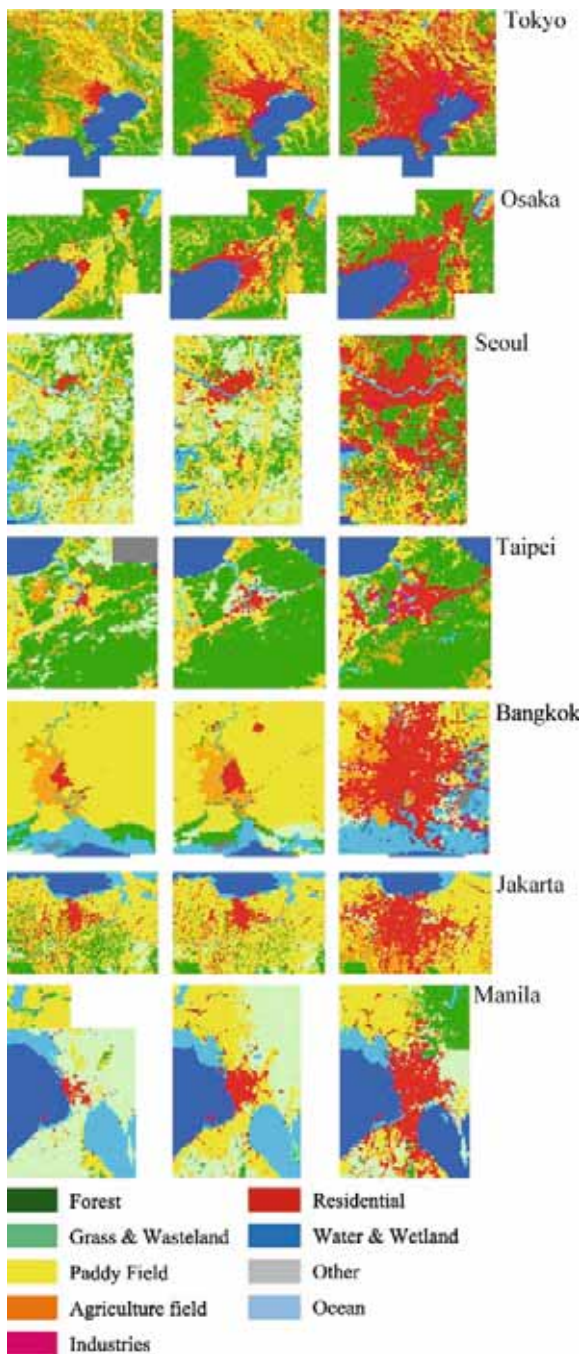


Fig. 1.8 Changes in land cover/use in seven Asian cities

Table 1.1 Changes in urbanized area including houses and industries in seven Asian cities

	1930		1970		2000		1930→1970	1970→2000
	(km ²)	(%)	(km ²)	(%)	(km ²)	(%)	(km ²)	(km ²)
Tokyo	891.3	6.2	1,644.5	11.4	4,509.0	31.3	753	2,865
Osaka	321.0	4.7	859.3	12.6	1,716.5	25.2	538	857
Seoul	72.5	2.0	264.3	7.3	1,214.8	33.7	192	951
Taipei	47.8	2.0	73.3	3.1	228.5	9.5	26	155
Bangkok	41.3	1.7	79.3	3.3	930.3	38.9	38	851
Jakarta	303.0	5.1	377.0	6.3	1167.8	19.5	74	791
Manila	78.3	2.4	214.3	6.0	638.5	17.7	136	424

Percentage shows the ratio of urbanized area of total area

Table 1.2 Groundwater natural capacity in seven Asian cities

	Aquifer thickness (m)	Area (km ²)	Storage (M ton)	Potential recharge rate (mm/year)	Residence time (year)
Tokyo	600	622	75	350	1,700
Osaka	1,200	222	53	430	2,800
Seoul	100	605	12	340	290
Taipei	100	272	5	640	160
Bangkok	500	1,569	157	450	670
Jakarta	100	740	15	640	160
Manila	300	632	38	820	370

The groundwater recharge rates were calculated with precipitation, evapotranspiration, and surface runoff from JRA

period when subsurface problems such as subsidence was first noticed and monitoring began. The fourth stage is the time when regulation of groundwater pumping began. The fifth and final stage is that period when groundwater is recovering and in some cases new subsurface problem (e.g., floating subway stations) started. According to these stages, Tokyo and Osaka are now in Stage 5, Seoul and Taipei are in Stage 4, Bangkok is in Stage 3, and Jakarta and Manila are in Stage 2.

In order to evaluate the natural capacities for the groundwater in each area, the groundwater storage (GS) with aquifer size and porosities, groundwater recharge (GR) rate which is the net result of evapotranspiration and surface runoff from precipitation, and the residence time (RT) which is calculated from groundwater storage and residence time ($RT = GS/GR$) were evaluated in the seven targeted cities, and the results are shown in Table 1.2. As can be seen, higher GS was found in Tokyo, Osaka and Bangkok, on the other hand, higher GR was found in Taipei and Manila followed by Bangkok and Jakarta.

Comparing Tokyo with each city shows that some cities benefit as developing later and from natural capacities such as higher groundwater recharge rate. However, the excessive development in Jakarta causes severe damage from land subsidence. Groundwater and subsurface environments as alternative, adaptation, and resilience to the changing environment should be treated with surface and coastal environments for better management and sustainable use.

Comparisons with natural capacities (groundwater storage, groundwater recharge rate, etc.) and changing society and environment indicators depending on the DPSIR model for urban groundwater problems in Asian cities clearly demonstrate that Asian coastal areas have the good potential for groundwater recharge, and it is possible to manage the groundwater resources sustainably in this region.

1.8 Conclusion

Several new methods have been developed in this study to evaluate the sustainable use of groundwater in Asia. Satellite GRACE, groundwater tracers, and 3D numerical simulations revealed the regional current groundwater status of the targeted areas in Asia, and showed the induced downward groundwater flow due to excessive pumping. Global warming and heat island effects as human and climate impacts on subsurface environments have been evaluated in several Asian cities. The analysis of subsurface temperatures showed that the subsurface thermal storage was greater when the magnitude of surface warming is higher and the elapsed time from the start of surface warming due to urbanization was longer. Analysis of land cover/use changes in seven Asian cities (Tokyo, Osaka, Seoul, Bangkok, Taipei, Jakarta and Manila) shows that urbanized areas expanded much faster from 1970 to 2000 compared to the measured increases from 1930 to 1970. Urbanization causes a decrease in the groundwater recharge rate and increases thermal transport into the subsurface environment. In order to develop integrated indicators for better understanding the relationships between human activities and the subsurface environment, the DPSIR model is used to analyze the relationships between social economic and subsurface environments depending on the stage in the model. Comparisons with natural capacities and changing society and environment indicators based on the DPSIR model for urban groundwater problems in Asian cities clearly demonstrate that Asian coastal areas have good potential for groundwater recharge, and it is possible to manage the groundwater resources sustainably in this region.

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References

- Burnett WC, Wattayakorn G, Taniguchi M, Dulaiova H, Sojisuporn P, Rungsupa S, Ishitobi T (2007) Groundwater-derived nutrient inputs to the Upper Gulf of Thailand. *Cont Shelf Res* 27:176–190
- Hosono T (2010) The nitrate-arsenic boundary as an important concept in aquatic environmental studies. In: Taniguchi M, Shiraiwa T (eds) *The dilemma of the boundary*. Springer (in submission)

- Huang S, Pollack HN, Shen Po-Yu (2000) Temperature trends over the past five centuries reconstructed from borehole temperatures. *Nature* 403:756–758
- Kagabu M, Shimada J, Nakamura T, Delinom R, Taniguchi M (2010) The groundwater age rejuvenation caused by the excessive groundwater pumping in Jakarta area, Indonesia. *J Hydrol* (under submission)
- Knorr W, Prentice IC, House JI, Holland EA (2005) Long-term sensitivity of soil carbon turnover to warming. *Nature* 433:298–301
- Taniguchi M, Shimada J, Tanaka T, Kayane I, Sakura Y, Shimano Y, Depaah-Siakwan S, Kawashima S (1999) Disturbances of temperature-depth profiles due to surface climate-change and subsurface water flow; (1) An effect of linear increase in surface temperature caused by global warming and urbanization in Tokyo metropolitan area, Japan. *Water Resources Research* 35:1507–1517
- Taniguchi M, Uemura T (2005) Effects of urbanization and groundwater flow on the subsurface temperature in Osaka, Japan. *Phys Earth Planet Inter* 152:305–313
- Taniguchi M, Uemura T, Jago-on K (2007) Combined effects of urbanization and global warming on subsurface temperature in four Asian cities. *Vadose Zone J* 6:591–596
- Taniguchi M, Burnett WC, Ness GD (2009a) Integrated research on subsurface environments in Asian urban areas. *Sci Total Environ* 404:377–392. doi:10.1016/j.scitotenv.2009.02.002
- Taniguchi M, Shimada J, Fukuda Y, Yamano M, Onodera S, Kaneko S, Yoshikoshi A (2009b) Anthropogenic effects on the subsurface thermal and groundwater environments in Osaka, Japan and Bangkok, Thailand. *Sci Total Environ* 407:3153–3164. doi:10.1016/j.scitotenv.2008.06.064
- Taniguchi M (2010) Subsurface environmental problems. In M. Taniguchi ed., *Subsurface environments in Asia*. Gakuho-sha (Japanese)
- Umezawa Y, Hosono T, Onodera S, Siringan F, Buapeng S, Delinom R, Jago-on KA, Yoshimizu C, Tayasu I, Nagata T, Taniguchi M (2009) The characteristics of nitrate contamination in groundwater at developing Asian-Mega cities, estimated by nitrate $d^{15}N$ and $d^{18}O$ values. *Sci Total Environ* 407:3219–3231
- Wang C-H (2005) Subsurface environmental changes in Taipei, Taiwan: current status. In: *Proceedings of RIHN international symposium on human impacts on urban subsurface environments*, October 18–20, 2005, Kyoto, Japan, pp 55–59
- Yamamoto K, Fukuda Y, Nakaegawa T, Nishijima J (2009) Landwater variation in four major river basins of the Indochina peninsula as revealed by GRACE. *Earth Planets Space* 59:193–200
- Yamano M, Goto S, Miyakoshi A, Hamamoto H, Lubis RF, Monyrath V, Kamioka S, Huang S, Taniguchi M (2009) Study of the thermal environment evolution in urban areas based on underground temperature distributions. *Sci Total Environ* 407(9):3120–3128



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