Urban Subsurface Environments

Newsletter Volume 10 October 2010

This is the last volume of our project's newsletter. The full implementation of the project "Human Impacts on Urban Subsurface Environment" continues in 2010 and the project members have conducted field experiments, surveys and data gathering in the target cities.

Summaries of the main results of all groups (Urban Geography group, Gravity group, Heat group, Material group, Water group and Social Economic group) are featured in this volume.

Inside this issue

Project Activities and Plans

Makoto Taniguchi, RIHN

This is the last news letter on RIHN-USE project "Human impacts on urban subsurface environment. The project have started in 2003 as incubation study, then feasibility study in 2004, pre-research in 2005, and full research from 2006 to 2010. More than 70 members are involved in this project. As a project leader, I acknowledge very much to all project members for achievements of this project. We had three international symposiums (IS) during the period. The first IS was held in Kyoto, Japan on 2005, and the second IS was held in Bali, Indonesia on 2007 as a side event of COP13. The third IS was held in Taipei, Taiwan on 2009. One more international Symposium on groundwater organized by RIHN, UNESCO-IHP, MEXT and others will be held in Kyoto on November, 2010.

More than 150 scientific papers were published related to this project and additional papers will come. Some papers were published in STOTEN special issue. Four PhD theses have been made related to this project and two more theses will be coming soon. Two English books, "From headwaters to the ocean" (CRC Press), and "Groundwater and subsurface environments in Asia" (Springer) are published, and three related books were also published including IAHS red book, IAH book series, and Springer on RIHN international symposium "Dilemma of the Boundary". Two Japanese books, "Subsurface environment in Asia" (Gakuho-sha) and "Urban and water environment in Asian cities" (Kokon-shoin) are also published based on this project. Another scientific picture book "Urban and water landscape in Asia" will be published in this year. The final results including all documents will be published in CD with many animations and pictures in this year.

In this project, we have evaluated the relationships between urban development and subsurface environment problems with integrated analyses beyond the two boundaries between surface/subsurface and land/ocean in Asian coastal cities. We have developed several new products including numerical modeling of the subsurface environment, new tracer techniques such as CFC's and Kr, Satellite GRACE data, new methods to reconstruct surface warming including global warming and heat island, and subsurface contaminant history from the sediments. Relationship between development stage of the city and subsurface environment problems have been also analyzed in this project with both integrated indices of changing society and environment, and natural capacity. Integrated indices, depending on DPSIR model was established with yearly basis for seven cities over 100 years (1900-2000). Five development stages of the city are recognized in Tokyo based on the DPSIR, and six other cities are compared with Tokyo for land subsidence, groundwater contamination, and subsurface thermal anomaly.

We plan to have three feedback seminars (FS) to show the project results in each city. The first FS will be held on November in Manila, and the second FS will be held in Jakarta on January, 2011, then the last FS will be held in Bangkok on February, 2011. We prepare to launch an Asian consortium on "Urban and water" at Bangkok on February, 2011.

I would like to acknowledge all project members, staffs and RIHN members as well as counterpart colleagues in each country. We could not achieve this project without their kind and sincere helps. Thanks again for their all supports during the RIHN-USE project.

The outline of the research of Urban Geography Group

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The research tasks of Urban Geography Group

The first research task is collecting the geographical data of the megacity for research. The second research task is clarifying the city origin and a subsequent development process. The third research task is clarifying the relation between urbanization and change of water environment. Otherwise, there are research tasks with main relation between urbanization and urban climate, relation between water environment and location of religion institution, etc.

Those research tasks will provide other research groups with fundamental data about the megacity for research. Furthermore, these research findings will carry out a big contribution also a geographical societies.

The main results of research

The cities for research are seven megacities in Asia as shown in Tab.1. Although each cities some of get mixed up, they will have the origin as a modern city around 1900. The development process of the subsequent cities differed, as shown in Fig.1. However, each city has the common feature in finally having formed conurbation city including a surrounding cities.

Fig.2 (example of Tokyo) showed the urban development process in model, and it is a land use map around 1930,1970 and 2000 in Fig.3. Many water environmental issues have arisen with urban development. Although the concrete water environmental issues are as having been shown in Tab.2, the part was solved as a result of taking measures with a natural thing. The observations in the research have revealed that there are time lags between megacities in terms of timings of water environment issue emergence and solution. Fig.4 showed this relation.

As a next step, an attempt will now be made to gain an organized time-series view as to how water environment issues have developed. Note that the water environment issues focused on here are limited to lower groundwater levels and land subsidence; these issues are examined to ascertain the timing at which any major change occurred to them.

Tab.1 The data on Metropolitan region on Asian Megacities

Megacities	Population (10,000persons)	Metropolitan Area(km²)	Population Density(person/km²)
Tokyo	3,425	7,835	4,350
Osaka	1,725	2,720	6,350
Seoul	1,950	1,943	10,050
Taipei	650	440	14,750
Bangkok	800	1,502	5,350
Jakarta	2,060	2,720	7,600
Manila	1,915	1,425	13,450

Source: Demographia(2009)

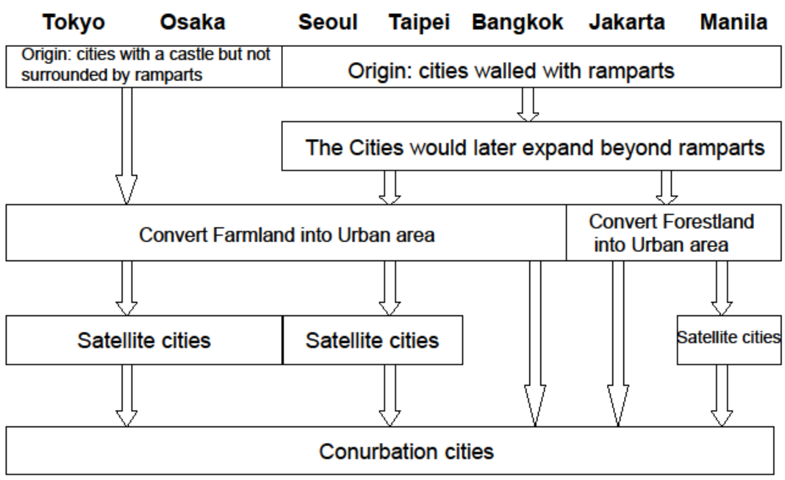

Fig. 1 The Process of Urban Development

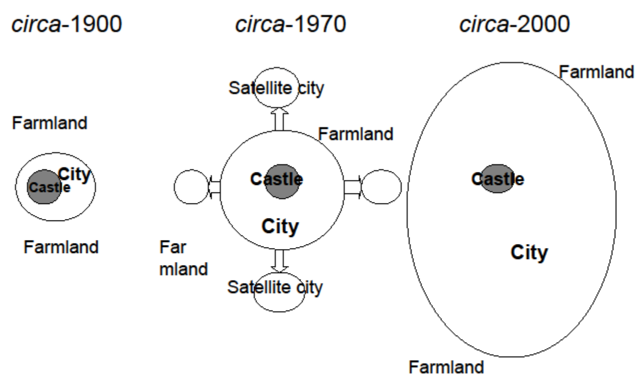

Fig. 2 Urban development model of Tokyo

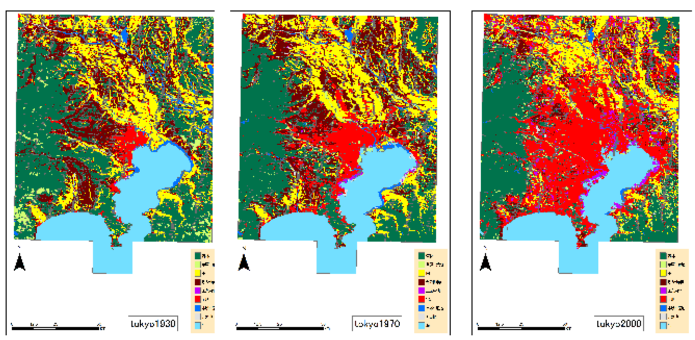

Fig. 3 Land use of Tokyo

Red:Residential land

Fig.2 (example of Tokyo) showed the urban development process in model, and it is a land use map around 1930, 1970 and 2000 in Fig.3. Many water environmental issues have arisen with urban development. Although the concrete water environmental issues are as having been shown in Tab.2, the part was solved as a result of taking measures with a natural thing. The observations in the research have revealed that there are time lags between megacities in terms of timings of water environment issue emergence and solution. Fig.4 showed this relation.

As a next step, an attempt will now be made to gain an organized time-series view as to how water environment issues have developed. Note that the water environment issues focused on here are limited to lower groundwater levels and land subsidence; these issues are examined to ascertain the timing at which any major change occurred to them.

Tab.2 Current state of water environmental issues

Items / Cities	Water environmetal issues: Ground water level	Land subsidence	Ground water salinization	Ground water pollution	Total	Sewage service coverage rate (%)
Tokyo	○	◎	◎	△	○	99.9
Osaka	○	◎	◎	△	○	99.9
Seoul	△	△	—	△	△	98.1
Taipei	○	△	○	—	△	60.1
Bangkok	△	×	—	×	×	50.0
Jakarta	△	×	—	×	×	1.0
Manila	△	×	—	×	×	5.0

◎very positive ○positive △somewhat problematic ×very problematic —un-inquiring

In every city, it is only after entering into a period of high economic growth that certain steps are taken to address water environment issues. As solving any water environment issue requires a proportionate amount of money, an economic backing is imperative. Fig.4 illustrates how those factors are connected with each other. Viewed by city group, Tokyo and Osaka entered into a high economic growth period in 1955, during which they managed to get out of the most serious stage of their water environment issues. The economy of Seoul and Taipei grew rapidly between 1980 and 1985. It is from then on that their water environment issues have been in the process of being solved. Equivalent economic growth started in 1980 in Bangkok, but it is only very recently that signs of the city getting over its water environment issues came into view. In the cases of Jakarta and Manila, where a high economic growth period began in 1990, water environment issues are still in their serious stage. Thus, it has now become clear that every city group has gone through, or is going through, a similar experience with time lags of roughly 20 years.

In the research, the urban development processes in the Asian megacities and resulting changes in their water environment were discussed, and the water environment issues that have emerged as a consequence were sorted out. As a result, it has been brought to light that the cities that developed early also saw water environment issues emerge early, but a good part of them are now in the process of being solved. This research stopped short of examining any specific actions taken to address those issues, but a remaining challenge is to apply in an effective fashion the approaches and experience of those cities to other megacities.

In conclusion, an attempt will be made to examine which aspects of Tokyo's or Osaka's experience must be communicated to other cities. As an example, the case of Bangkok will be discussed. Bangkok has gone through its urban development and the emergence of water environment issues with a time lag of approximately 30 years compared to Tokyo or Osaka. Looking back at how it used to be in Tokyo and Osaka three decades ago, Japan was frantically trying to control its surging demand for water. What Tokyo and Osaka did back then was having water saved to the furthest extent possible. Specific examples were: charging a lot for water, promoting the reuse of water in factories, etc., and facilitating the broader use of water-saving appliances in factories and at home, etc. Efforts were also made to prevent leaks in waterworks and reduce unnecessary water use. Depending on the weather conditions, however, droughts took place and water-saving awareness needed to be raised by means of publicity. Now, 30 years on, the issues that were pending then have been solved to a considerable extent and Tokyo and Osaka are now water-saving-minded cities. It is unclear in what form Tokyo's or Osaka's experience could be put into action in, for instance, Bangkok, but it might be worth trying a few approaches in this light.

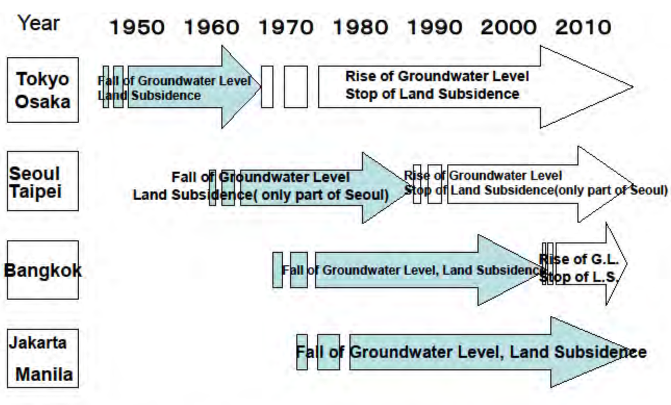

Fig.4 Change of Water Environment Issues

As a city develops, changes occur to its water environment, such as a decrease in the area of its waters. Such changes would result in reduced groundwater recharge or might also diminish water retention and other functions served by the surface ground, possibly making it vulnerable to floods. It is a very important task to assess what changes in water environment lead to water environment issues to what extent, but there is still very little understanding of these questions. Presumably, a challenge remains for us to answer them in the future by studying a particular megacity.

In megacities, however, a whole new issue has emerged in relation to water: floods. Global-scale changes in climatic conditions (*e.g.*, global warming, sea level rise, so-called guerilla downpours) have resulted in local-scale flood damage. Megacities, however, remain virtually inept at dealing with this phenomenon. In all likelihood, this issue will also need to be brought into focus in the future.

Photo. High tide disaster in Jakarta, December,2007

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The main research achievements

(Books)

T.Endo 2008 A Comparative Policy Analysis for Headwater Management. M. Taniguchi, W.C. Burnett, Y. Fukushima, M. Haigh, Y. Umezawa (ed.) From Headwater to the Ocean-Hydrological Changes and Management. Taylor & Francis Group. , pp.131-136.

(Papers(Original Articles))

K. Kataoka, F. Matsumoto, ,T. Ichinose, ,M .Taniguchi 2009 Urban Warming Trends in Several Large Asian Cities over the Last 100 Years.. *Science of the total environment* 407 :3112-3119.

A. Yoshikoshi, ,I. Adachi, ,T. Taniguchi, Y. Kagawa, M. Kato, A. Yamashita, ,T. Todokoro and M.Taniguch 2009 Hydro-environmental changes and their influence on the subsurface environment in the context of urban development. *Science of the total environment* 407 :3105-3111.

T. Taniguchi 2008 The restoration of Historical Hydro-environment from Historical Materials and Topographical Maps in Tokyo, Japan. M. Taniguchi, W.C. Burnett, Y. Fukushima, M. Haigh, Y. Umezawa (ed.) From Headwater to the Ocean-Hydrological Changes and Management. Taylor & Francis Group, pp.565-569.(reviewed).

T. Endo 2008 A Comparative Policy Analysis for Headwater Management. M. Taniguchi, W.C. Burnett, Y. Fukushima, M. Haigh, Y. Umezawa (ed.) From Headwater to the Ocean-Hydrological Changes and Management. Taylor & Francis Group, pp.131-135.

A. Yamashita 2008 Urbanization and the change of water use in Osaka City - Spatio-temporal analysis with data maps. M. Taniguchi, W.C. Burnett, Y. Fukushima, M. Haigh, Y. Umezawa (ed.) From Headwater to the Ocean-Hydrological Changes and Management. Taylor & Francis Group, pp.571-575.

Y. Kagawa 2008 Urbanization in Asian Metropolis and the Changes of hydrological environment in and around Bangkok. M. Taniguchi, W.C. Burnett, Y. Fukushima, M. Haigh, Y. Umezawa (ed.) From Headwater to the Ocean-Hydrological Changes and Management. Taylor & Francis Group, pp.571-575.

Report of the Gravity Group

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1. Introduction

In RIHN project 2.4, the main theme of the gravity group is "Monitoring of the ground water variation in urban area by combining GRACE data and in-situ gravity measurement". Practically the gravity group aims at developing new techniques to monitor the groundwater variation by means of precise gravity measurements on land and from space as well. For this reason, slightly different from other groups, the target cities of the gravity group are restricted to mainly Jakarta and Bangkok. Instead, we have conducted some test measurements for the in-situ gravity measurements in Japan, and also have extended the test areas for the application of the satellite gravity data.

Regarding the in-situ gravity measurements, we introduced a field type absolute gravimeter, Micro-G LaCoste Inc. A10 (A10-#017) on Dec. 10 2007 (Fig. 1). So far, only two A10 gravimeters have been imported to Japan. The first one, which is belong to National Defense Academy of Japan, has been used mainly in a laboratory and the knowhow of the field measurements was practically nought before this project. Therefore, in this project, we have been conducting several test measurements in the field not only to confirm the accuracy of the instrument but also to investigate the practical and efficient measurement methods for field surveys. Some technical reports are found in previous Newsletters (No.5, No.7 and No.9) and some reference articles (*e.g.* Fukuda *et al.*, 2010) as well. In chapter 2 of this report, we summarized the gravity measurements.

Regarding the applications of the satellite gravity, we have employed the GRACE (Gravity Recovery and Climate Experiment) data. Using the GRACE data, we first estimated the seasonal variations of TWS (Terrestrial Water Storage) in four major basins of the Indochina Peninsula, and compared them with those estimated from Soil-Vegetation- Atmosphere Transfer Scheme (SVATS) models (Yamamoto *et al.*, 2007; Fukuda *et al.*, 2009). The results show good agreements between GRACE and model TWSs basically. In addition to the seasonal variations, we have revealed the interannual TWS changes. In chapter 3, we summarized the GRACE data analysis.

TWS models are important not only for the comparison with the GRACE data but also to link the space observation and in-situ measurements. It is obvious that there are large differences in temporal and spatial resolutions between satellite and in-situ gravity measurement. However we expected these differences could be resolved by hydrological models. This is the main reason why the gravity group has been conducting the TWS model improvements. In addition, we conducted some simulation studies for the applications of the future satellite missions. In chapter 4, these issues are summarized.

Fig.1. A10 #017 gravimeter (Micro-g LaCoste Inc.).

2. Gravity measurements

2-1. Measurements in Kyushu University Ito campus

In order to check the repeatability of the measured gravity values, we have repeatedly conducted the measurements at the gravity point in Ito campus, Kyushu University. Fig. 2 shows the measured gravity values from Jan. 2008 to Nov. 2009. There are three groundwater monitoring wells near the point and the groundwater levels are also shown in Fig. 2. The gravity values showed a good correlation with the groundwater levels. It means that A10 can be used for monitoring the groundwater levels. In addition we can estimate the effective porosities at the wells are from 9.4 to 21.7% because an infinite water table of 1 meter thickness causes about a 40-mgal gravity change. Taking into account the gravity changes due to the groundwater variations, the repeatability of the A10 measurements looks better than 10 μgals.

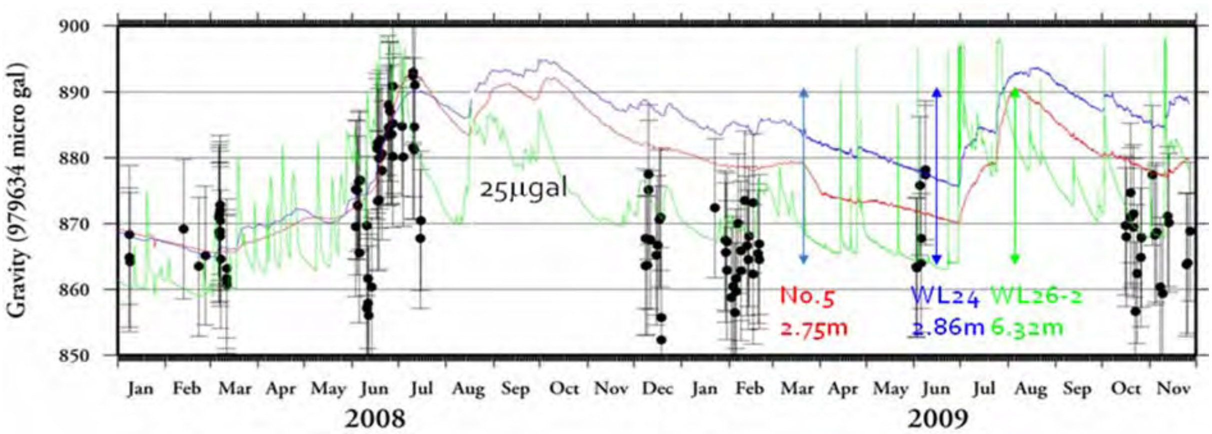

Fig. 2. Absolute gravity measurements by A10 in Ito Campus, Kyushu University. No.5, WL24 and WL26-2 show the groundwater variations at the nearby observation wells. Scales of the groundwater variations are converted to "mgals"according to the factors obtained by liner regression analyses.

2-2. Repeated measurements in Takigami geothermal area

Takigami geothermal field is located in the southwestern part of Oita prefecture, central Kyushu, Japan. The Takigami power plant (25MW) was completed in November 1996. The production depth is about 2500m and the reinjection depth from 1000m to 1500m. The amount of production is about 1300 ton/hour (12Mt/year), and about the 85% of production (1100 ton/hour) is reinjected to the underground to prevent the ground subsidence.

During the normal operation of geothermal plant, mass balance at both production and reinjection wells are attained and no gravity change is observed. In April 2008, the cycle of the geothermal fluid was stopped for a regular maintenance of the power plant. As shown in Fig.3, we selected the 4 stations (T13, T19, T26 and T27), and conducted the repeat gravity measurements from Feb. 2008 to Mar. 2010, before and after the maintenance (Fig. 4). We observed a gravity decrease of 19 micro gal just after the maintenance in the reinjection zone (T-26A). After that, the gravity values recovered in December, 2008. These changes seem to be caused by stop of reinjection. On the other hand, we detected small gravity increase (4.4 micro gal) just after the maintenance in the production zone (T-27A).

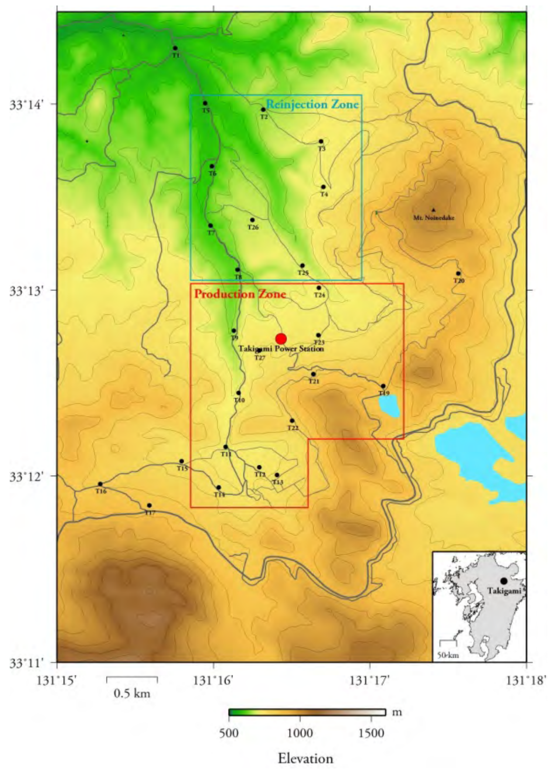

Fig. 3. Distribution of observation points around Takigami geothermal power plant.

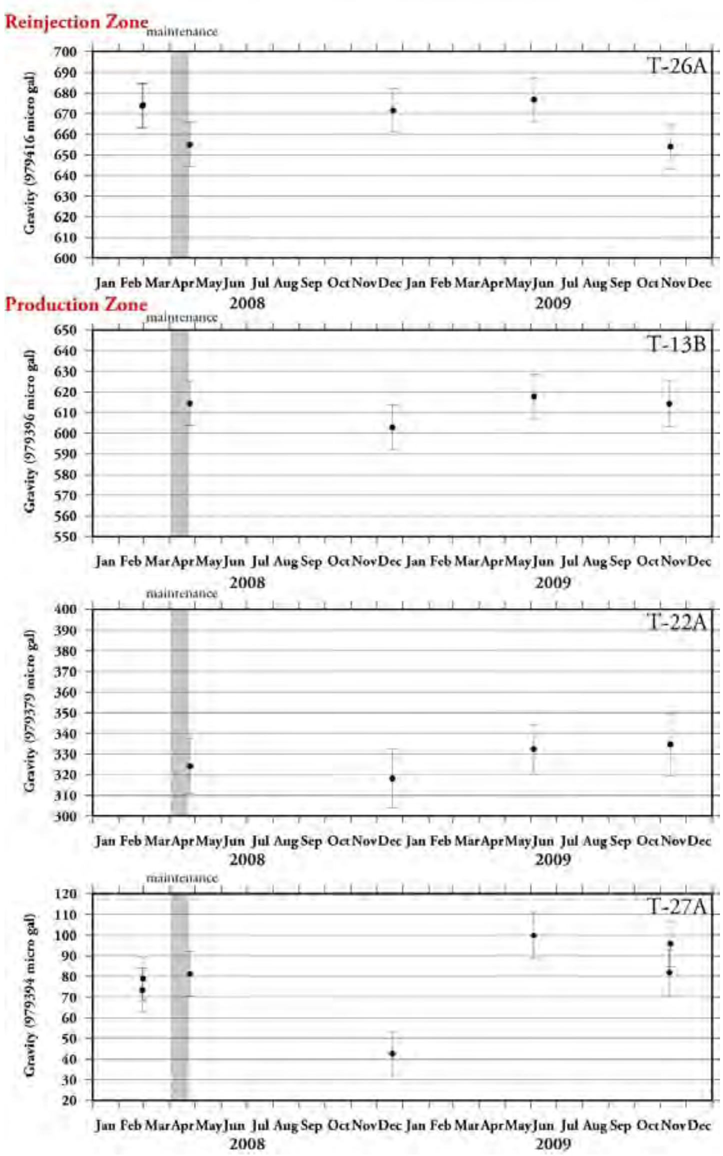

Fig. 4. Variation in absolute gravity (micro gal) from 2008 to 2009 in the Takigami geothermal field.

2-3. Surveys in Indonesia

In order to detect the gravity changes caused by groundwater level changes, we repeatedly carried out the gravity and GPS survey in Jakarta, once a year in July-September. Using A10-#017, the first absolute gravity measurements have been conducted in Sep. 2008. Actually these measurements in 2008 were not so satisfactory mainly due to instrumental problems. We obtained only limited number of absolute gravity values.

After the 2008 survey, the gravimeter was returned to the manufactory for overhaul. Also we have improved the measurement methods. Consequently, we succeeded to measure absolute gravity values at 6 points in 2009 and 2010. In addition, using a relative gravimeter (CG-3M), we measured the gravity values at 9 stations. Using these data, we obtained the gravity changes at 4 points, although the final absolute gravity values have not been available due to calibration reasons. Fig. 5 shows the gravity changes observed by the relative gravimeter and the land subsidence observed by the GPS survey. Gravity increases were observed in these stations. The sense of gravity changes correspond with ground subsidence. But it seems that the amount of gravity changes are too big, and we need to calibrate these gravity changes using the absolute gravity data.

Fig. 5. Comparison between the relative gravity changes (micro gal) and ground subsidence from 2009 to 2010 in Jakarta.

3. GRACE data analysis

3-1. Role of the GRACE data

Although one of the main purposes of this project is to investigate local groundwater systems on and around the urban cities, the project also aims to understand large-scale landwater movements including the target cities. GRACE data have been widely used for the studies of landwater variations, because temporal variations of the gravity field are mainly caused by landwater variations. One of the advantages of the GRACE observation is that it can detect variations of total TWS including groundwater over large area. It is almost impossible to detect the total TWS by other methods. In this study, we used GRACE data sets for the study of seasonal and interannual TWS variations over the Indochina Peninsula, where one of the test cities, Bangkok, is located on.

3-2. Seasonal TWS variations

Seasonal TWS variation is one of the most prominent signals, which can be detected by GRACE. Over the Indochina Peninsula, especially, the signals are large due to the Southeast Asian Monsoon climate. We recovered the seasonal TWS variations in four major river basins of the Indochina peninsula, *i.e.* the Mekong, Irrawaddy, Salween and Chao Phraya basins by GRACE data. We revealed that the GRACE data was useful to recover the variations of the basin scales (spatial scales) of ~300 to 400 km. The estimated TWS variations were compared with those calculated from different versions of the global-scale terrestrial water storage model, JRA-JCDAS LDA and GRiveT Terrestrial Water Storage Model (JLG).

We first detected about 1-month phase differences in the comparison of an old version of the JLG (TWS1 described in Chapter 4) and the GRACE TWS (Yamamoto et al., 2007). After that, the JLG model has been improved by taking into account of the following effects; 1) explicit groundwater components, and 2) river current speeds tuned for each of river basins. The latest version of the JLG (TWS3 in Chapter 4) showed a good agreement with the GRACE-derived seasonal TWS variations (Fukuda et al., 2009.) This means that GRACE data contributes to the improvement of global-scale landwater models.

3-3. Seasonal TWS variations

GRACE has constantly provided the data since its launch in 2002. At present, almost 10 years GRACE data are available, and analyses of the interannual mass variations can be possible. After removing the seasonal variations, we estimated the interannual TWS mass variation over the Indochina Peninsula. Fig. 6 shows the mass variations. Fig. 6 clearly shows the bend of the trend at around the beginning of 2004. The trend decreased until the beginning of 2004, and after that, it increased until 2009. To reveal the main source of the trend change, we compared the GRACE-derived TWS with several models and different kinds of observations. For the comparison with a local groundwater model, the trend change observed by GRACE was estimated much larger than the trend due to the local groundwater change, which was mainly caused by the excessive groundwater pumping and the subsequent recovery. This seemed to suggest the trend change could be related to more large scale phenomena. After correlation analyses with several indices of the large scale phenomena, we found that the trend change showed negative correlation with the Dipole Mode Index (Fig. 7). The Dipole Mode Index is the climate index which represents Indian Ocean Dipole phenomenon. Therefore we concluded that the observed interannual mass change over the Indochina Peninsula was caused by global-scale meteorological event rather than by the local effects such as the impacts of human activities.

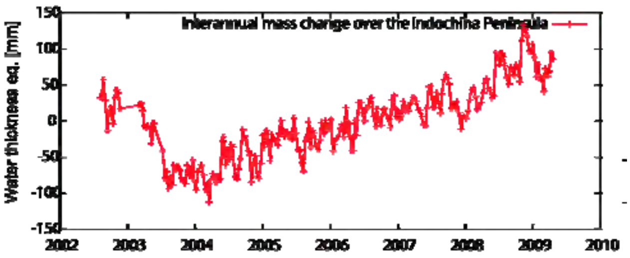

Fig. 6. GRACE-derived interannual TWS mass change averaged over the Indochina Peninsula derived after removing annual and semiannual components.

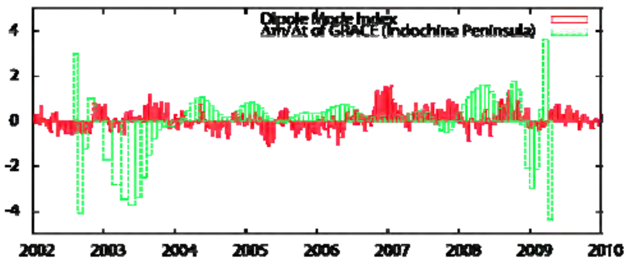

Fig. 7. Comparison of Dipole Mode Index provided by UNESCO and Δm/Δt of the GRACE-derived interannual TWS change.

4. Improvement of TWS models.

We produced terrestrial water storage (TWS) from the Land Data Analysis (LDA) routinely performed by the Japan Meteorological Agency (JMA) for validating TWD derived from gravity satellite missions such as GRACE and CHAMP. In this project, we have upgraded the TWS by introducing reasonable hydrological processes:

1. at the first stage, TWS consists of snowpack, soil moisture, and river channel water storages (TWS1),
2. at the second stage, the seasonal phase of river discharges has been tuned, and river channel water storage was modified (TWS2), and
3. at the final stage, shallow groundwater storage has been introduced, and the seasonal phase of river discharge has been re-tuned (TWS3).

We compare estimated TWS2 with available independent TWS. The TWS3 slightly improve in seasonal temporal correlation and phase difference when we compare TWS3 with TWS2. However it scarcely improves in TWS amplitudes. The implementation improves both river discharge and TWS correlation coefficients and phase differences for the estimated TWS without the tuning, or TWS1, but the tuning can compensate for the drawbacks due to no implementation of the groundwater scheme.

In addition, we developed the terrestrial mass change dataset. It includes soil moisture, snowpack, river channel water storage, and groundwater storage as TWS components, and aeolian dust and sediment transports as natural phenomena, crude oil, coal, and natural gas, iron, and bauxite mining as anthropogenic phenomena. We examined the seasonal amplitude of the TWS and found that soil moisture covers most areas as the largest annual range at monthly time-scale. At the interannual time-scale, geographical distribution is basically similar to that of the monthly time-scale except for the replacement of snowpack to soil moisture in high latitudinal regions. Detectability of these mass changes by a satellite gravity mission is examined and the mass decreases due to aeolian dust and sediment transports, and mining are detectable in regions with large signals within 20 years under an ideal condition where the almost TWS signals can be removed with the estimated TWS. Fig. 8 shows (a) the mass change due to coal mining and (b) the ratio of the annual mass change to the standard deviation of the interannual variability of the annual mean TWS or trend (T) - standard deviation (σ) ratio. We assess the detectability of the mass change due to the coal mining under the assumption that mass change data with GRACE-level accuracy are available for a sufficiently long period. The largest *T/σ* ratio is about 1/yr, suggesting that it takes only one year for the reduction in mass change due to coal mining to become equivalent to the interannual variability of the annual mean TWS. These results provide basic but new information about hydrological features of TWS and mass changes.

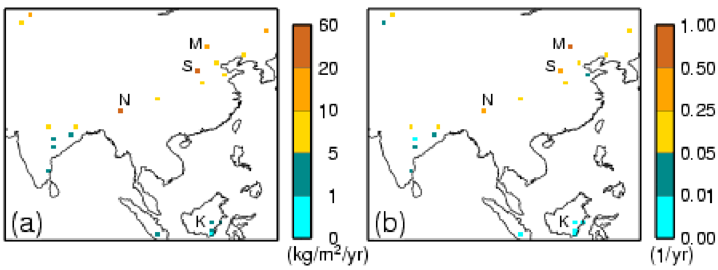

Fig. 8. (a) Mass change due to coal mining and (b) T/σ ratio. K, M, N, and S represent the Kalimantan Island, Nei Mongolia, the North East coal fields, and Shanxi respectively.

5. Concluding remark

The sustainable use of groundwater is a key issue for future urban developments, and the gravity technique, which is new and still challenging, should contribute to monitor the groundwater variations, because only gravity measurements can detect the mass variations directly. This is the most important point that we have employed gravity measurements on land and from space as well for the studies. The gravity data can provide the most basic information to manage the urban water usability together with other hydrological information such as the groundwater levels measured at observation wells.

Regarding the in-situ gravity measurements, we considered that the use of absolute gravimeters was essentially important and we extensively conducted the test measurements using the A10 gravimeter. Through this project, we have accumulated useful techniques and knowhow in the field gravity measurements. There is no doubt that they should contribute for the future studies.

The spatial resolution of the GRACE data is far from satisfactory for discussing urban scale groundwater variations. However, GRACE provides very good constraint for hydrological models in terms of total mass variations. It should be noted again that there was no such high precision constraints as the mass variations before GRACE. In the future, several different scale models would combine much advanced in-situ and satellite observations for a better understanding of the hydrological processes.

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Evolution of subsurface thermal environment in urban areas

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Temporal variation in the ground surface temperature (GST) slowly propagates downward and disturbs the subsurface temperature structure. It means that records of GST variation in the past are stored in subsurface sediments and basement rocks. It is therefore possible to estimate the history of GST through analysis of vertical temperature profiles measured in boreholes. Reconstruction of GST history with this method may be an effective tool in studies of thermal environment evolution in urban areas.

We, the Heat Group, have investigated the subsurface thermal anomalies in large cities in East Asia caused by human activities mainly through measurements of borehole temperature profiles and long-term temperature monitoring (Yamano et al., 2009). The obtained borehole temperature data were used for reconstruction analysis of history of recent surface warming and evaluation of the amount of heat accumulated in the subsurface in and around the target cities. The long-term temperature records in observation wells provided information on actual downward propagation process of GST variations. We briefly report main results of these studies below.

Temperature profile measurements in observation wells

Since 2004, we have been conducting measurement of temperature profiles in boreholes in the target cities (Seoul, Bangkok, Taipei, and Jakarta) and their surrounding areas (Fig. 1; Table 1). The total number of measurement stations as of 2010 is 112. Most of the measurements were made in groundwater monitoring wells because they are well maintained and used mainly for passive monitoring and geological and hydrological information is often available. Most of the measured profiles showed negative (or close to zero) temperature gradients within 50 to 100 m of the ground surface (Fig. 2). It indicates recent GST increase due to global warming and/or the heat island effect.

Except for the Seoul area, where the wells are rather shallow and the temperature profiles were disturbed by pumping, we made repeated measurements to examine the stability of temperature profiles. The total number of measurement stations in Table 1 is less than the sum of the number for each survey because of such repeated measurements. We found that the temperature profiles in some wells varied with time (Fig. 3), which probably resulted from temporal variation in groundwater flow around the wells.

Table 1. Borehole temperature measurements in and around large cities in East Asia.

City	Survey Time	Number of Stations	Measurement Depth
Seoul	Sep. 2005	14	14 – 88 m
Bangkok	Jul. 2004	27	40 – 401 m
	Jun. 2006	19	
	Mar. 2008	16	
	Feb. 2010	9	
		Total 44	
Taipei	Nov. 2005	11	60 – 308 m
	Jun. 2007	18	
	Jan. 2009	14	
	Feb. 2010	5	
		Total 26	
Jakarta	Sep. 2006	28	40 – 252 m
	Aug. 2007	12	
	Aug. 2008	6	
	Feb. 2009	2	
		Total 28	

Fig. 1. Temperature profile measurement in a groundwater monitoring well in the Jakarta area.

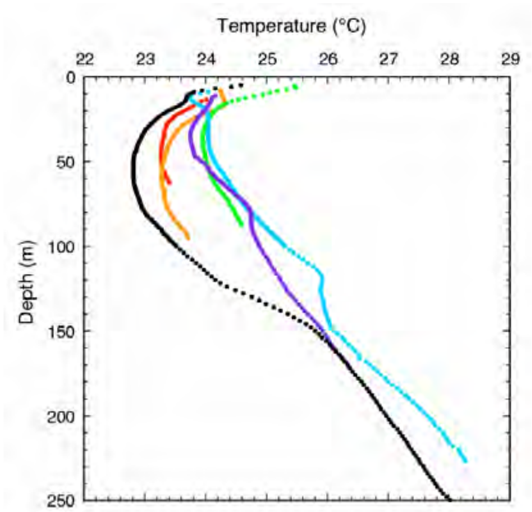


Fig. 2. Examples of borehole temperature profiles measured in the Taipei area jn 2009.

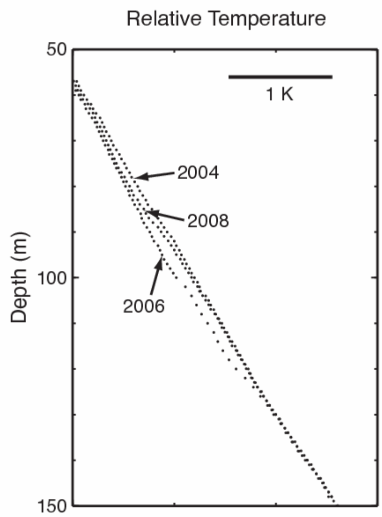


Fig. 3. Temporal variation of temperature profile observed in a well in the Bangkok area (Hamamoto et al., 2009).

GST history reconstruction

In addition to temperature profiles obtained through the surveys mentioned above, we collected existing borehole temperature profile data in the Tokyo, Osaka, and Seoul areas and selected data suitable for reconstruction of GST histories (profiles not influenced by groundwater flow). We used a multi-layer model for GST reconstruction analysis (Goto and Yamano, in press), which assumes horizontally layered structures and allows thermal properties to vary from layer to layer. Since the target cities are developed on alternating coarse and fine deposits, it is essential to take variability of thermal properties into consideration.

In the Bangkok area, we could successfully reconstruct GST histories at six sites through inversion analysis of the borehole temperature profiles (Hamamoto et al., 2009). Although the estimated GST increased in the last 100 to 150 years at all the sites, the amount of increase significantly varies by site (Fig. 4). The temperature increase after 1900 is as much as 2.5 K in the central part of Bangkok, only 0.4 K in a rural area, and between them at the sites in suburbs of Bangkok. It suggests that the GST increase is mainly due to influence of urbanization or human activity, including the heat island effect and land use change.

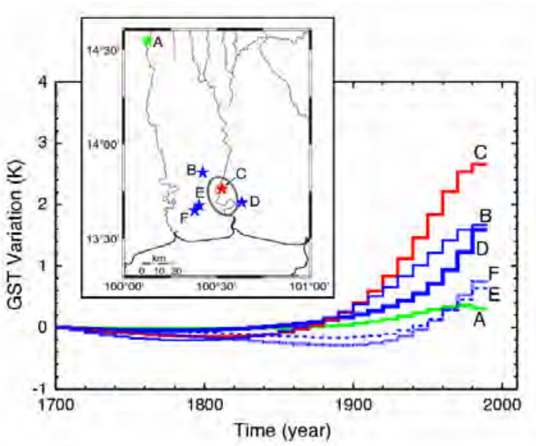


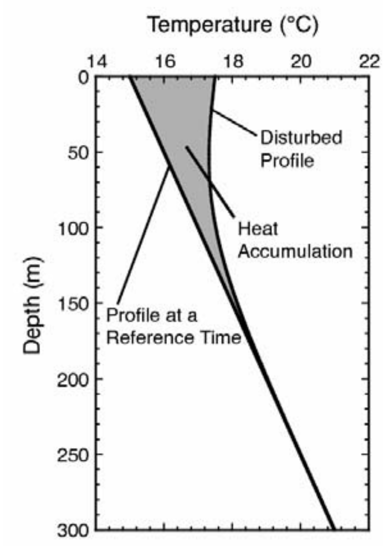
Fig. 4. GST histories reconstructed at six sites in the Bangkok area (Hamamoto et al., 2009).

Subsurface heat island

Significant GST increase in the last 50 to 100 years caused a temperature rise in the subsurface of the target cities. It means that "subsurface heat island" has been formed in response to development of heat island above the ground in these cities (Miyakoshi et al., 2009a). We may be able to detect the subsurface heat island effect through repeated measurements of borehole temperature profiles at intervals of several years or longer. Miyakoshi et al. (2009b) compared the temperature profiles in 2001 to 2002 and those in 2005 to 2006 in the Tokyo area and showed that the subsurface temperature increased during this period. The rate of temperature increase is higher in the central part of Tokyo than in suburban areas.

The amount of heat accumulated in the subsurface per unit area can be calculated by integrating temperature anomaly. In Fig. 5, the area of the gray part multiplied by the heat capacity of the subsurface material represents the amount of heat stored since the reference time. It can therefore be easily estimated at sites where GST history reconstruction was made. Hamamoto et al. (2009) calculated how the heat stored in the subsurface has increased since 1900 at the six stations in the Bangkok area (Fig. 6). The heat accumulated at the city center between 1900 and 1990 exceeds 200 MJ/m^2, more than the double of the average over Eurasia and North America. The amount of the stored heat may be regarded as an indicator of the evolution of subsurface thermal environment and should be useful in multidisciplinary study on environmental changes in urban areas.

Fig. 5. Accumulation of heat in the subsurface (gray part) as a result of temperature increase caused by surface warming.



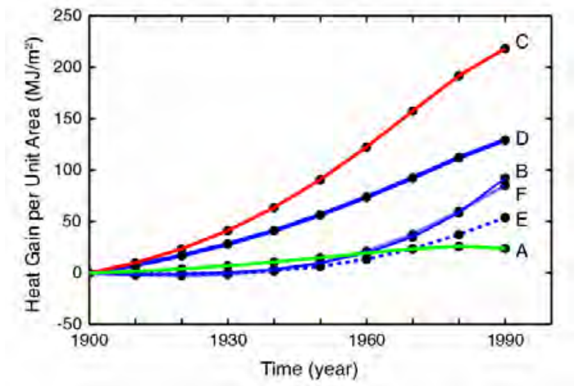


Fig. 6. Amount of heat stored in the subsurface after 1900 at the six sites in the Bangkok area (stars in Fig. 4) calculated based on the reconstructed GST histories (Hamamoto et al., 2009).

Long-term temperature monitoring

We made temperature monitoring in boreholes to observe downward propagation process of GST variation. The most detailed measurement has been carried out in a borehole in the Lake Biwa Museum located about 20 km east of Kyoto. We installed a cable with 10 thermistor sensors at 15 m to 130 m below the surface and have been monitoring the temperatures since September 2007 (Fig. 7). The temperature record at 15 m has a strong annual component, which is obviously attributed to propagation of the annual variation at the surface. The 15 m temperature also shows a long-term increase at a rate of about 10 mK/year. Slow and steady temperature increases at similar rates are observed at 20 to 40 m as well. These long-period components are interpreted to be related to change(s) in the thermal environment at the surface associated with construction of the museum in 1994, which covered the ground surface around the hole. The temperature records in this borehole demonstrate influence of human activity on subsurface thermal environment.

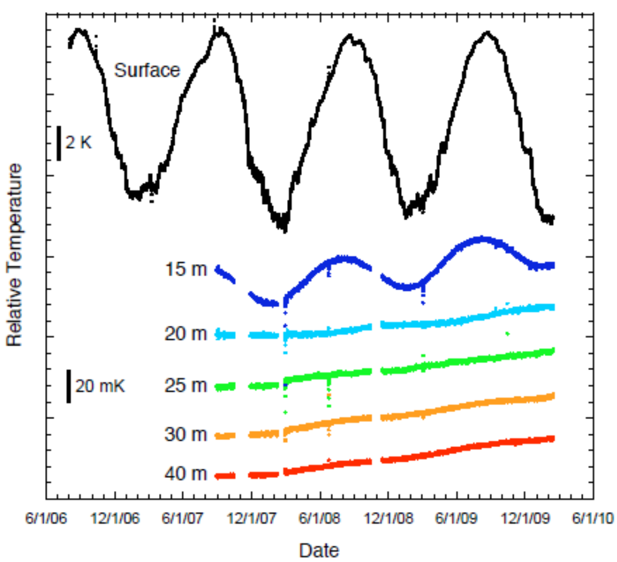


Fig. 7. Long-term temperature records obtained in a borehole and at the surface in the Lake Biwa Museum, Japan.

In other boreholes, we installed self-contained water temperature recorders at three depths, 30 to 50 m in most cases (Fig. 8). The longest record (for about 2.5 years) was obtained in a well in the Taipei area (Fig. 9). It shows monotonous temperature increase at all the three depths (29.1, 34.2, and 39.4 m below the surface) except for two anomalous events and the rate of increase is higher at shallower depth. Most of the observed temperature increase may result from downward propagation of influence of recent surface warming (the heat island effect).

Fig. 8. Installation of water temperature recorders in an observation well in Taiwan.

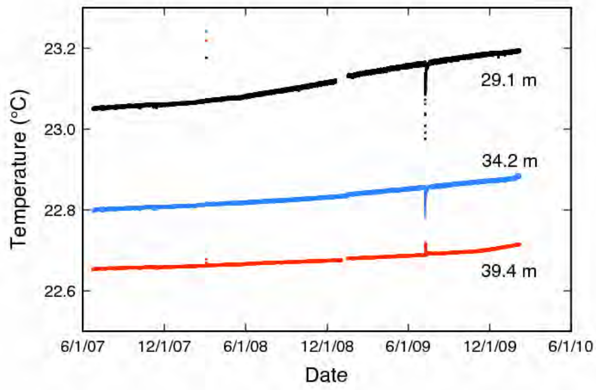


Fig. 9. Temperature records for about 2.5 years at three depths in an observation well in the Taipei area.

We also conducted monitoring of soil temperatures at shallow depths aiming to estimate the present GST and to obtain information on the heat transfer process just below the ground surface. Temperature sensors were buried within 1 m of the surface beside some of the wells where temperature profiles were measured. Temperature records obtained 0.43 m and 0.93 m below the surface at a station in southern Taiwan show typical features of thermal diffusion process, attenuation of amplitude and phase shift (Fig. 10). Analysis of the data indicates that heat transfer between the two depths is almost conductive and the thermal diffusivity is estimated to be about 8×10^{-7} m^2/s, consistent with previously reported values for shallow subsurface material.

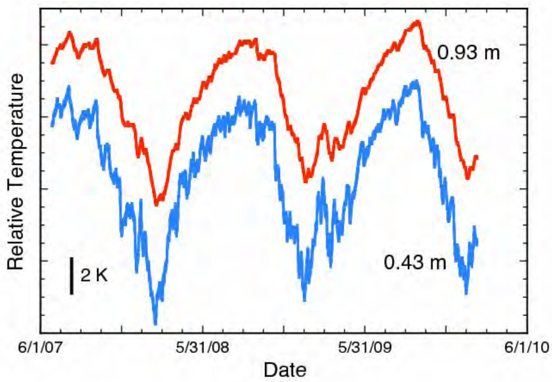


Fig. 10. Variation of soil temperatures at shallow depths at a site in southern Taiwan.

Such soil temperature records can be used for examination of the relationship between the surface air temperature (SAT) and GST, because the annual mean of shallow soil temperature must be nearly equal to that of GST. In the Osaka area, information about the GST and SAT relationship was obtained through analysis of borehole temperature profiles at six sites by Huang et al. (2009). They calculated subsurface temperature disturbance assuming that GST variation is approximated by SAT variation recorded at a meteorological station in the city center. The calculated disturbance is smaller than the observed one at all the sites, indicating that the rates of GST increase at these sites were higher than that of SAT at the meteorological station.

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Results of Material Group of the Project

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Introduction

We had already summarized our results in RIHN International Workshop in Taipei in November, 2009 and we have published the book of Springer and Gakuhosya. In this news letter, I want to show some topics from these books.

Research Member

Our group was composed of Japanese members, and field counterpart members in Korea, Taiwan, Philippine, Thailand, and Indonesia. 9 Japanese members participated in field researches during this research period.

- Core member: Shin-ichi Onodera (Hiroshima Univ.), Takanori Nakano (RIHN), Takahiro Hosono (Kumamoto University), Yu Umezawa (Nagasaki University), Shinji Nakaya (Shinsyu University), Mitsuyo Saito (Ehime University), Kazuhiro Ohkawa (Akita University), Jun Yasumoto (Ryukyu University) and Tomotoshi Ishitobi (Nara city).

- Student member: Yuta Shimizu, and Yoshiaki Kato (Hiroshima Univ.)

In addition, our group has conducted the researches in all mega-cities of 6 countries. The international members in all countries have supported our activities and managed the monitoring system.

New framework of pollution in megacities

In this research, the various subsurface pollutants associated with urbanization were confirmed, such as nitrate, trace metals, and chloride. In general, the vulnerability of megacities to pollution is found to be high but the variation for each city is not clear. In this chapter, an indication of this is suggested by the intensities of surface pollution (flow) and subsurface pollution (accumulation). These intensities are controlled by human impact as well as the natural background, as shown in Fig. 1. For example, the emission and load of pollutants increase with the population creating surface pollution in the first stage of city development. Then, subsurface pollution occurs as surface pollutants are transported to the groundwater. In addition, groundwater abstraction affects the intrusion of surface pollution to deep groundwater. On the other hand, contamination and attenuation processes related to groundwater flow conditions are controlled by the natural features such as topography, geology, watershed area, and natural recharge or climate. In the case of Bangkok, the topographic gradient is very small and the natural recharge is also small. Hence, the attenuation rate of nitrate by denitrification is relatively large, while chloride contamination by palaeo-salt is serious.

The estimated vulnerability of Asian megacities to the various pollutants is shown in Fig. 2. The horizontal axis represents the surface pollution and the vertical axis represents the subsurface pollution. It is suggested that the vulnerability to each pollutant is determined by the natural environment and the developing stage of each city. These components control the groundwater flow conditions related to the oxidation-reduction reaction and the pollutant load by human activity. In this diagram, the vulnerability is higher in the top right area and is low at the bottom left area. A city in the first stage of development, going through an intensive growth of population, is plotted at the bottom right area, whereas the cities in the third stage, which are in the developed stage with infrastructure, are plotted on the top left area. The estimated vulnerability of Jakarta to nitrate, trace metals, and chloride contamination is high, Bangkok is extremely vulnerable to chloride but less vulnerable to nitrate, and Osaka is highly vulnerable to As and chloride.

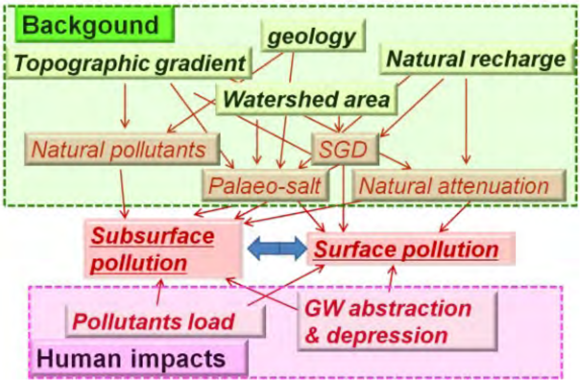

Fig. 1 Controlling factors of vulnerability to pollution.

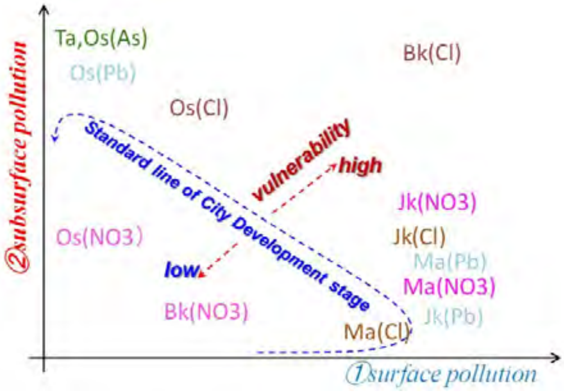

Fig. 2 Vulnerability of coastal megacities to different pollutants.

Bk: Bangkok, Jk: Jakarta, Ma: Manila, Os: Osaka, Ta: Taipei

New topics of subsurface pollution in megacities

As described below, we have constructed the new framework of pollution in megacities in this research, based on many results of hard works by all members. I want to introduce the new some topics here. Those are as follows:

1) Accumulation amount and source of nitrate pollutions in megacities were confirmed in Jakarta, Manila, Bangkok, Taipei, Soule, and Osaka (see the news letter in last year).

2) Denitrification intensities in groundwater of five megacities were verified, using N and O isotope of nitrate, and dissolved gas.

3) Accumulation amount and source of trace metal and chloride pollutions in megacities were also confirmed in each city. Fig. 3 shows the relationship between nitrate and arsenic concentrations in various Asian megacities (Hosono et al., submitted). The high As concentrations were detected in the aquifers with a reductive condition as well as a high ammonium concentration, such as in Bangkok, but the nitrate concentration indicated an opposite trend.

4) We detected less terrestrial submarine groundwater discharge but huge material flux by total SGD. In addition, spatial variation in SGD was estimated in Jakarta bay (Fig. 4) and Osaka bay, using Rn tracer (Umezawa et al., 2009) and topographic model (Shimizu et al., 2009).

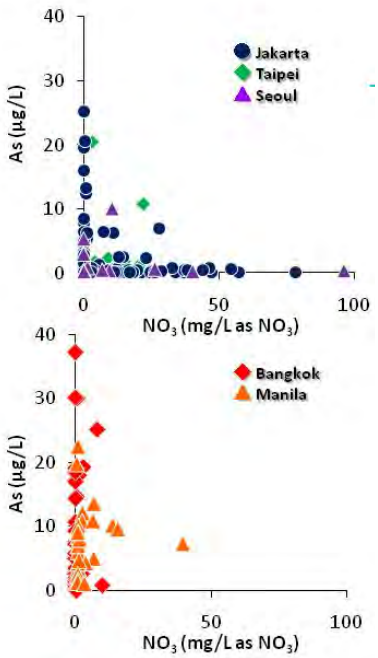

Fig. 3 Relationship between nitrate and arsenic concentrations in various Asian megacities. (Hosono et al., submitted)

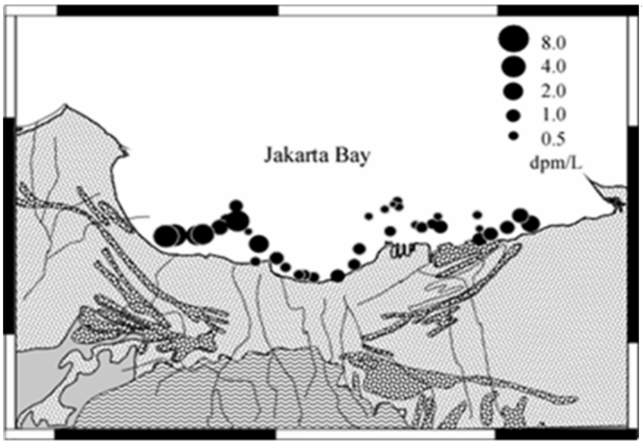

Fig. 4 Distribution of 222Rn concentrations along the coastal line in Jakarta Bay. (Umezawa et al., 2009)

5) We will reconstruct organic pollution and metal pollution histories, using marine sediments. In addition, the differences of the peak in each trace metal were confirmed.

6) We are monitoring SGD and material load in Bangkok and Jakarta as well as in Manila, using automated seepage meter and piezometers. Unfortunately, we could not collect data in Manila, because of electrical trouble and maintenance problem. We are collecting continuous data by the improvement of maintenance method. Photo 1 and 2 show aspects of the observation sites in Jakarta and Bangkok, respectively.

Photo 1 Aspect of SGD observation site in Bangkok.

Photo 2 Aspect of SGD observation site in Jakarta.

7) We are also going to evaluate the natural purification in groundwater of nitrate pollution and the application of ultrasonic technique to decomposition of organic chloride compounds.

a) Mass balance of nitrate, ammonium, and gas nitrogen and nitrogen isotopic component suggest denitrification potentials in groundwater of each city. Fig. 5 shows the example of results in Jakarta (Saito et al., 2009).

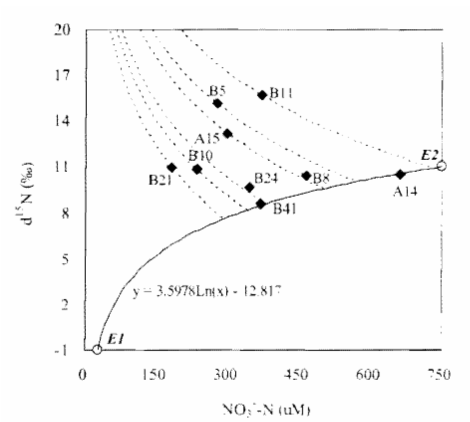

Fig. 5 NO_3^--N and $\delta^{15}N$ relationships in groundwater of Jakarta. (Saito et al., 2009)

E1 is a spring water in a forest headwater, E2 is nitrate polluted groundwater with high nitrate concentration.

b) The ultrasonic technique applied to purification of organic compounds by Okawa was confirmed to be high performance in laboratory. The schematic diagram of this system is shown in Fig. 6. This will be applied to the in situ purification in future.

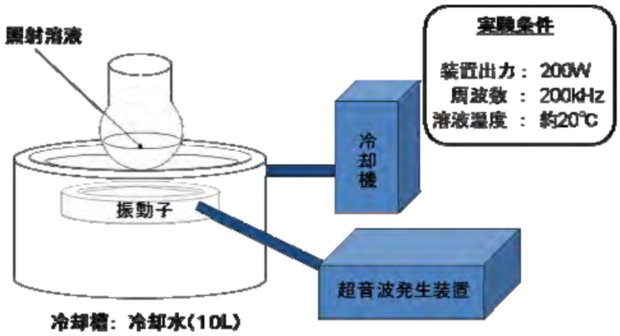

Fig.6 schematic diagram of the ultrasonic-technique applied to purification of organic compounds. (Okawa et al., submitted)

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Results of Water Group of the Project

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(This is digest article from "Chemical and physical evidences in the groundwater aquifer caused by over-pumping of groundwater and their countermeasures in the major Asian coastal cities" by Jun Shimada, which will be published from Springer.)

Most Asian coastal cities has experienced serious groundwater disasters during recent 50 years caused by the over-pumping of regional groundwater related with the abrupt demand of groundwater resources linked with the urban economic growth. These situations have started initially at Osaka area, Japan in 1960's, then after Tokyo and Nagoya areas in 1970's. As these economically important Japanese cities developed on the alluvial coastal sediments, the related groundwater disasters are either huge land subsidence or salt-water intrusion in the coastal areas. As there was no unified national groundwater law in Japan, the groundwater disaster-related prefectures cooperated to establish the groundwater regulating audiences over the problem area. National governments helped to construct the alternative infrastructure of surface water supply system for the industrial and city water demands. Because of those countermeasures, the groundwater disasters in the previous Japanese three large cities has almost disappeared within 30 years periods, which is surprisingly quicker than the most hydro-geologist's prediction. This quick recovery of the depleted groundwater potential can be explained by the positive groundwater recharge potentiality of Japanese island, which belongs to the warm humid hydrological region.

A similar groundwater disaster has been expanding to the major Asian coastal cities, such as Taipei, Shanghais, Manila, Bangkok, Jakarta, etc., which grows under the framework of the delayed economical expansion of the Asian nations within the 40 years after 1970's. Some cities like Taipei and Bangkok has succeeded to control such groundwater disasters using the similar way as Japan. However, cities like Jakarta and Manila has still in the serious problem and has not found their correct way-out.

In this project, we have conducted the comparative study of the coastal Asian cities for their groundwater problems. Japanese large cities has experienced severe groundwater disasters during 1960 and 1970's and succeeded to recover by the effective groundwater pumping regulations. Many Asian coastal cities like Taipei, Shanghai, Bangkok, Manila, and Jakarta have similar groundwater disasters 10 to few 10 years late after Japan. Some cities like Taipei and Bangkok has succeeded for the recovery of their groundwater potentials but many cities are still in the problem and seeking for the better solution. Although there exists the historical difference depend on the economical development steps for these cities, the groundwater problems in the coastal Asian cities shows the similar historical trends and it is said to be possible to recover based on their hydrological setting of coastal Asia. Followings are the concluding remarks of this section.

Over-pumping at urban area creates the groundwater disasters such as land subsidence, sea water intrusion, oxygen air deficit problems, etc. and also 'the induced groundwater recharge' at the depression area of groundwater potential, these include;

① forced recharge at the recharge area of the target aquifer

② squeezing from the upper and lower confining bed of the target aquifer

③ intrusion of the shallow groundwater through the confining bed which has confirmed

by the groundwater age component such as CFCs, ^{3}H and ^{14}C

Coastal Asia has the potential recharge capacity based on its hydrological setting and its maximum recharge rate should be P-AE. Because of this, it is possible to regulate and manage the groundwater resources in Coastal Asia. To succeed in the regulation, the infrastructure of surface water supply and the background of national groundwater act is key issue. Also understanding the hydro-geological setting of the local aquifer and the evaluation of the maximum recharge capacity of the area is important for the effective groundwater management. The historical groundwater disaster and its recovery experience of Japanese large cities can contribute much for the cities in coastal Asia.

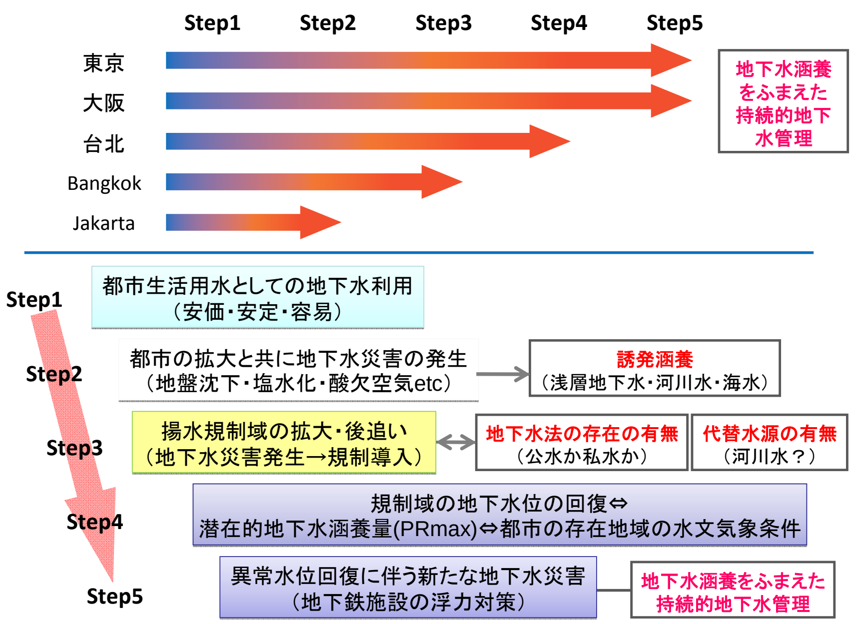

Figure 1. The differences of the development steps in the coastal Asian cities.

Results of Social Economy Group of the Project

Shinji Kaneko

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(This is digest article from "Long-term urbanization and land subsidence in Asian megacities: An indicators system approach" by Shinji Kaneko and Tomoyo Toyota, which will be published from Springer.)

A city is a place where population is highly concentrated and so human activity is spatially intensive. This particular property also strengthens as the city develops economically in the long run. In the dynamic process of city development, various environmental problems take place sequentially. At the same time, the city is equipped with the capacity to cope with these problems alongside its development process. In some cases, specific environmental stresses and damage in the city tend to be more acute during certain stages of city development, and this phenomenon is typically represented by the environmental Kuznets hypothesis (Bai and Imura, 2000). Using past battles against urban environmental problems in the developed world, we can draw the lesson that preventive measures are difficult but still cost effective compared with any ex-post countermeasures.

As urbanization is a global megatrend, no nation worldwide has developed effective policies to address its challenges. In particular, many developing countries in Asia face the formidable challenge of urbanization with large populations and rapid economic development. Importantly, although the urbanization rate in Asia is currently relatively low at 40.8% in 2007, it is projected to grow to 66.2% by 2050 (UN, 2008). This suggests that some 1.8 billion new urban residents will be added over the next four decades to the urban population in Asia. Therefore, preventive measures against urban environmental problems should be considered to maximize the latecomers' advantage for developing Asia. In order for policymakers to undertake effective preventive measures, it is then important to recognize the long-term relationships between the urban development process and environmental problems and anticipate the occurrence of these important issues.

Fortunately, many of the lessons concerning urban environmental problems are well documented and already in practice in international environmental cooperation projects. However, the urban environmental issues analyzed in the past concentrate exclusively on air pollution, surface water pollution and waste management in cities. With this in mind, we focus on uncovered subsurface environmental issues in cities as a relatively new issue for developing Asia. As a first step, we collected existing knowledge and information from the literature and synthesized it into a Driving Forces-Pressure-State-Impact-Response (DPSIR) framework (Jago-on et al., 2009). Building on our previous work, the current study attempts to develop a stage model on the long-term relationship between urban development and the emerging subsurface environmental problem of land subsidence, and then compare the differences and commonalities across Asian developing countries. With the help of the DPSIR framework, we select and quantify the relevant indicators for each component of the requisite framework. The selection and construction of the indicators depicting the causality are conducted using the DPSIR framework developed in Jago-on et al. (2009). Concurrently, a stage model for land subsidence with urbanization is also developed. As a result of the indicators of DPSIR framework and the stage model, we can characterize each of the cities as follows: Taipei as an effective user of its latecomer advantage, Bangkok as a beneficiary of its natural capacity, and Jakarta and Manila at risk of unaddressed overdevelopment. Moreover, Osaka is characterized as a city overcoming its disadvantage in natural capacity when similar experiences in Tokyo are observed.

To cope effectively with land subsidence in developing megacities, a strategic and long-term perspective is required. A policy mix of both immediate countermeasures, such as regulation, and strategic long-term measures, such as the development of alternative water supplies, is strongly suggested for megacities when land subsidence is recognized. The timing of the various countermeasures, however, needs to be properly investigated in order to minimize any long-term social costs. In this regard, this analysis will be of some assistance in providing policy relevant information from a comparative perspective to maximize the advantage for latecomers to this key problem.

One of the main limitations of this study is information availability. Importantly, the accumulation of more reliable and accurate information would improve the quality of analysis and consequently help to provide more concrete and specific policy prescriptions for each city. Therefore, especially for latecomers like Jakarta and Manila, advances in monitoring, scientific research and the collection of the relevant socioeconomic indicators are highly recommended.

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Project 2-4 Human Impacts on Urban Subsurface Environments

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Human Impacts on Urban Subsurface Environments

This project will 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 and density have expanded rapidly and uses of subsurface environmental have increased. The primary goal of this project is to evaluate the relationships between the development stage of cities and various subsurface environmental problems, including extreme subsidence, groundwater contamination, and subsurface thermal anomalies. We will address the sustainable use of groundwater and subsurface environments to provide for better future development and human being.

ANNOUNCEMENT

Feedback Seminars

"Human impacts on urban subsurface environments"

To mark the final year of the project, the Socio-economic group organizes a series of feedback seminars in Metro Manila, Jakarta and Bangkok. The objectives of the seminars are to share the findings in our research and to receive feedback from and exchange information with experts in relevant agencies and research institutes in the Philippines, Indonesia and Thailand. These seminars will also be good opportunities to discuss future collaboration for research and policy advocacy on issues of the subsurface environment. The first part of the seminar will consist of presentations from RIHN on the research findings of the project. In the second part, there will be presentations on the current issues and future challenges on the subsurface environment, from representatives of national and local government agencies in each metropolitan area.

The seminar in Metro Manila will be on November 3, 2010, 1pm at the Marine Science Institute (MSI), University of the Philippines-Diliman in Quezon City. The feedback seminar in Jakarta will be on January 6, 2011 at the Indonesian Institute of Sciences. The seminar in Bangkok is tentatively set on February 24-25, 2011. During the seminar in Bangkok, some research collaborators and representatives from government agencies in the Philippines and Indonesia will also be invited to participate.

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