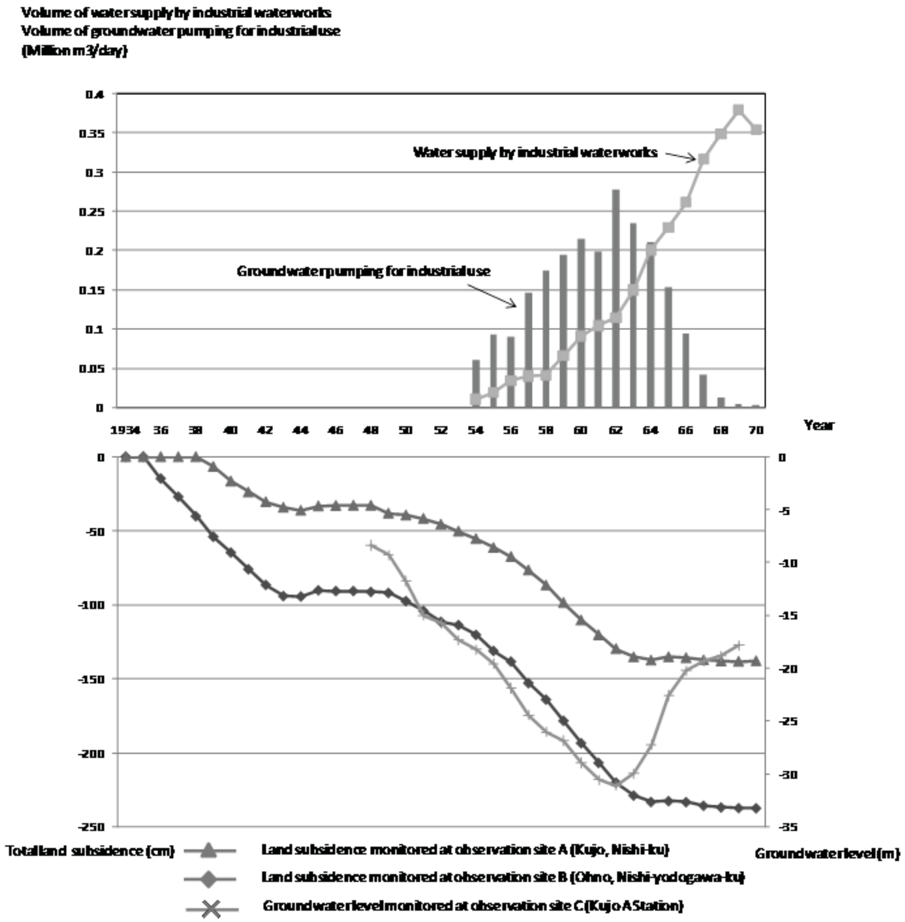
—OSAKA—

The City of Osaka

The City of Osaka has abundant water resources, and has flourished as a commercial city since ancient times as a “city of water” that uses marine transportation. Full-scale industrialization began in the second half of the 19th century, and Osaka grew into Japan’s largest industrial city, while the air pollution caused by smoke emitted from factories became a serious problem, to the extent that people started to call it the “city of smoke.” It began to tackle the pollution problem in the 1960s and by the 1980s it had largely solved the major problems. The population of Osaka Prefecture was 1,650,000 people in 1900 and expanded to 8,820,000 people (2,620,000 people in the City of Osaka alone) by 2005 and it is continuing its development as an important commercial city not only within Japan but also internationally.

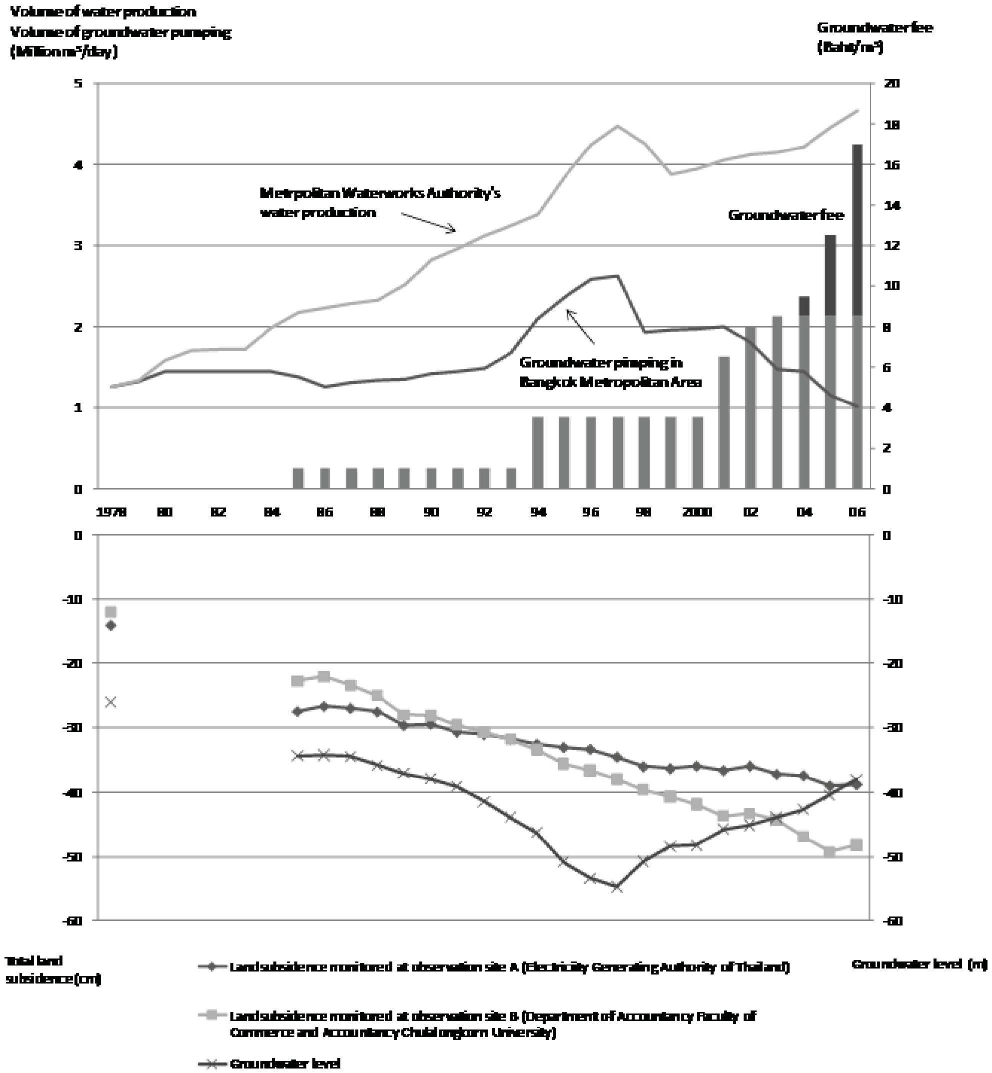
Solutions to Problems of Land Subsidence

Takahiro Endo（University of Tsukuba)・Shinji Kaneko(Hiroshima University) ・ Karen Ann Bianet Jago-on(RIHN)



Osaka's solutions to problems of land subsidence

In Osaka, groundwater was mainly used for industrial purposes. Problems of land subsidence were taken seriously after significant subsidence occurred with the Muroto typhoon of 1934. The Industrial Waterworks Law was enacted in 1956 (and later revised in 1962), and the Building Water Law was enacted in 1962. Under these laws, waterworks expanded in Osaka and groundwater users were required to change their water supply from groundwater to surface water. This change helped to mitigate land subsidence in Osaka.



Bangkok's solutions to problems of land subsidence

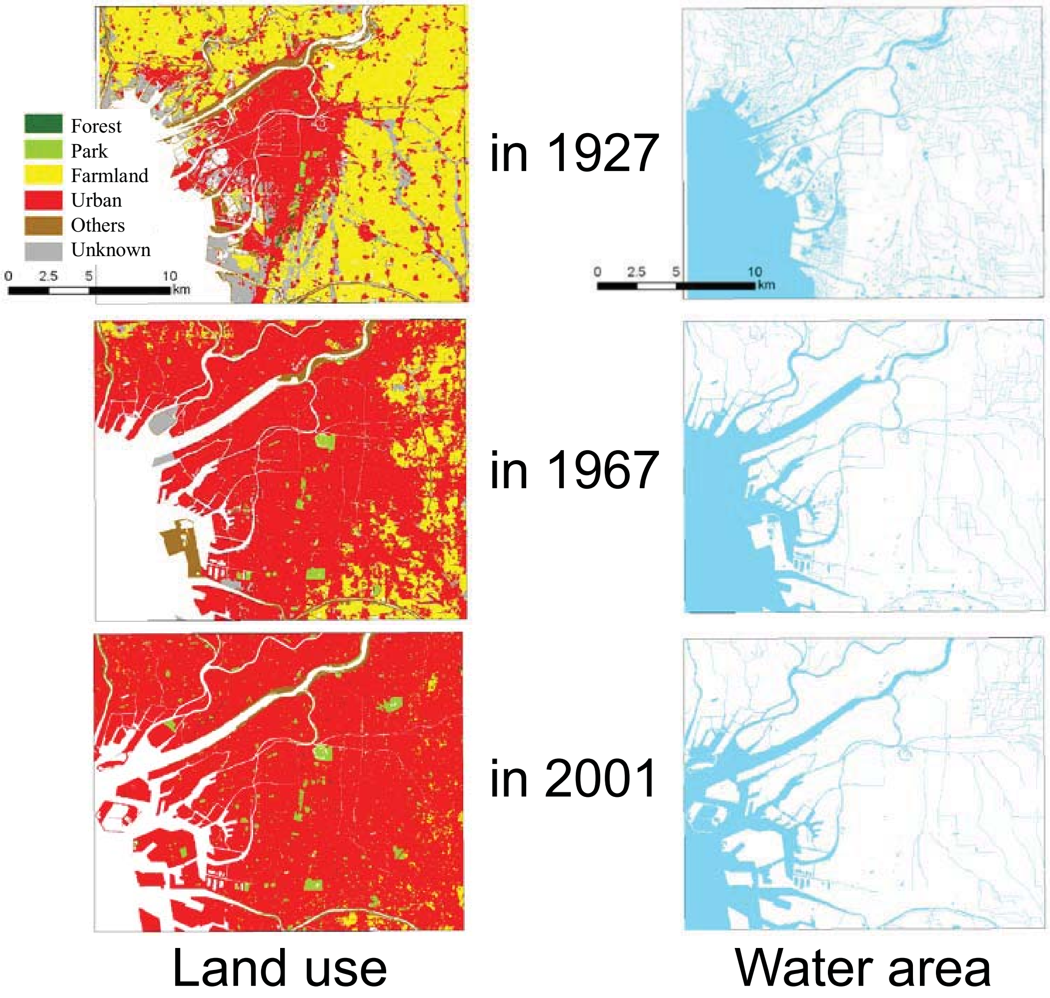
A comprehensive survey of groundwater, conducted from 1978 to 1981, identified an increased risk of flooding, after revealing rapid land subsidence in eastern and south-eastern Bangkok. The main cause of the subsidence was the excessive pumping of industrial groundwater. Various countermeasures were implemented, such as the enactment of groundwater laws, designation of pumping-restricted areas, expansion of waterworks, and a groundwater pricing system. Bangkok was successful in stopping land subsidence using theses countermeasures, with the groundwater pricing system proving to be a unique countermeasure, and one not seen in Osaka.

Takahiro Endo, "Sinking Cities and Governmental Action- Institutional Responses to Land Subsidence Problem in Osaka and Bangkok" in M. Taniguchi ed. *Groundwater and subsurface environment in Asia*, Springer, forthcoming.

Takahiro Endo, "The Case for Government in Groundwater Management: A Case Study on Land Subsidence Problem in Bangkok," *Journal of Japanese Association of Hydrological Sciences,* forthcoming.

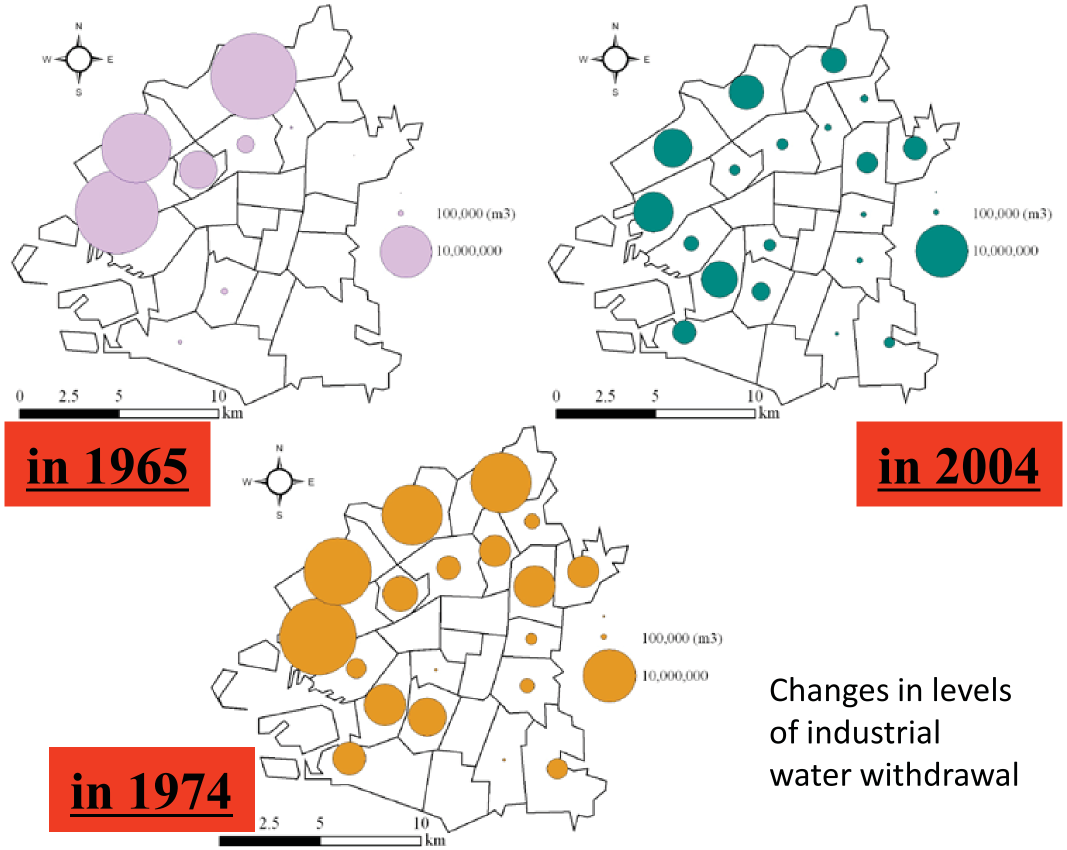
Urbanization and Changes in Water Use: Spatio-temporal analysis using Data Maps

A. Yamashita (University of Tsukuba)・M. Kato (Ritsumeikan University)

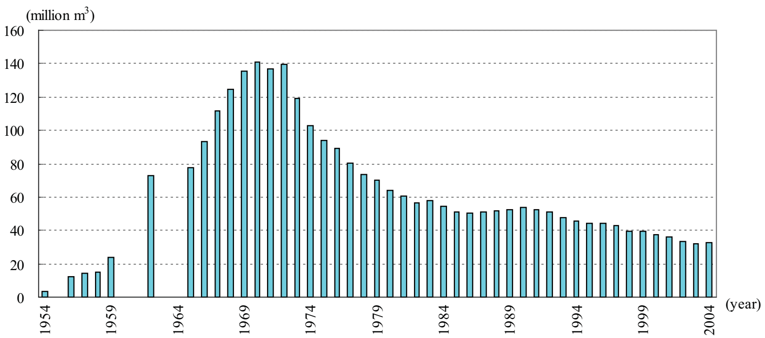


This study uses data maps to illustrate urban development and the changes in residential and industrial water use over the last 100 years.

The following datasets were used: data on land use and water areas were sourced using 1:25000 topographic maps published in 1927, 1967, and 2001; and temporal data regarding levels of water supply from waterworks and industrial water withdrawals.



Changes in levels of industrial water withdrawal



By the 1960s, urban areas had expanded outward and land use shifted from permeable to impermeable land. While groundwater was generally used to supply water to industries, the industrial water supply system was extended and the water source gradually shifted to surface water.

The changes in land use and water sources altered the pattern of travel for water in urban areas from three- to two-dimensional, one which does not involve underground traveling.

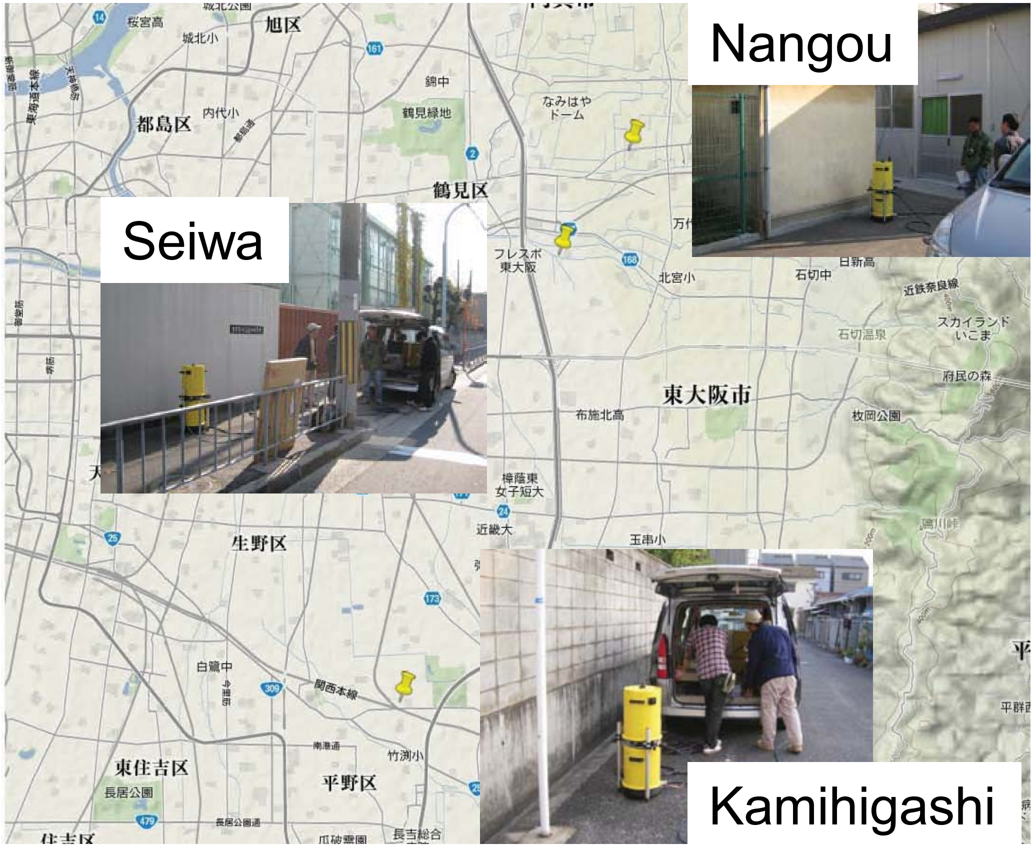
・Yamashita, A. (2009) “Urbanization and the change of water use in Osaka City -Spatio-temporal analysis with data maps” in Makoto Taniguchi et al. eds. *From Headwaters to the Ocean: Hydrological Changes and Watershed Management*, 571-575.
・Yoshikoshi, A., Adachi, I., Taniguchi, T., Kagawa, Y., Kato, M., Yamashita, A., Todokoro, T., and Taniguchi, M. (2009) "Hydro-environmental changes and their influence on the subsurface environment in the context of urban development" *STOTEN*, 407, 3105-3111.

Groundwater in Osaka

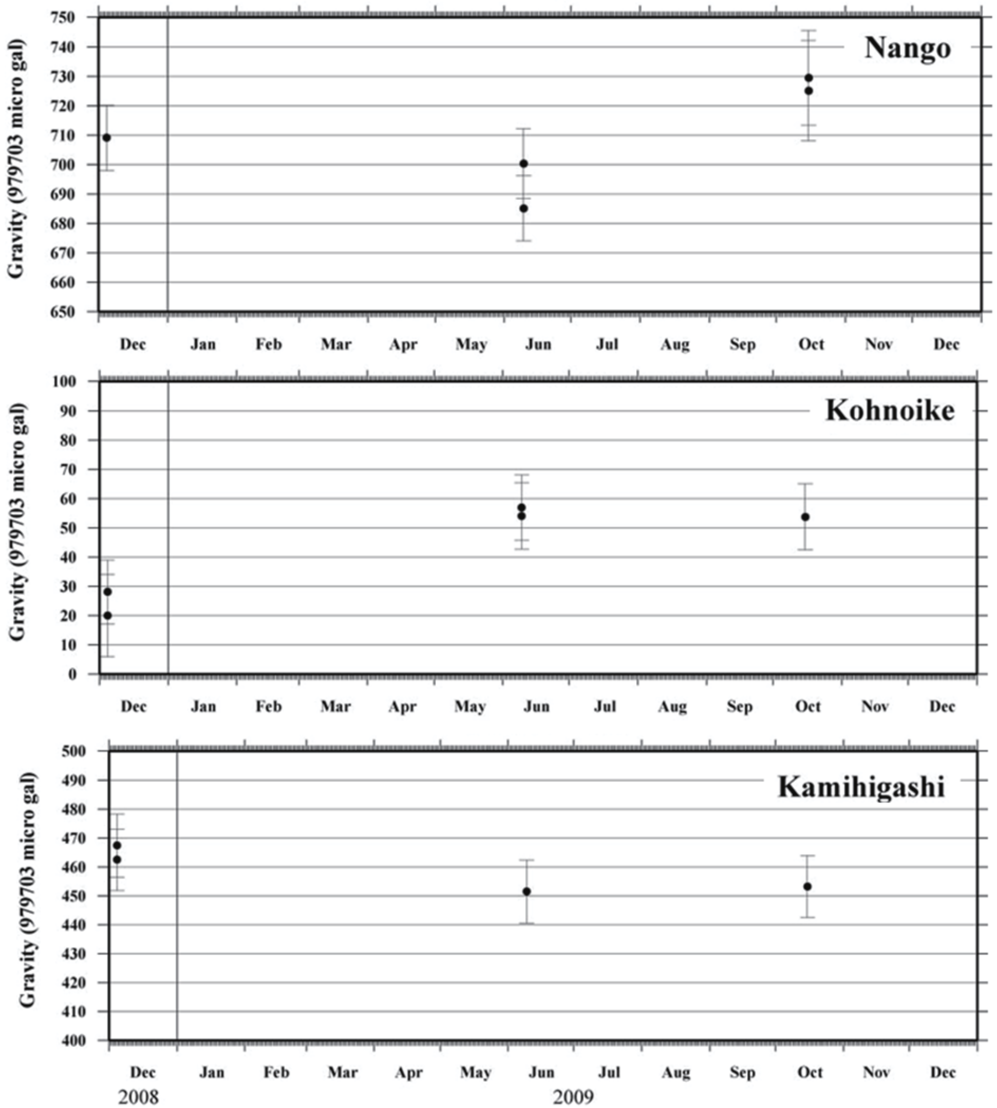
Just as in Tokyo, large amount of groundwater were pumped due to the industrialization and as a result Osaka experienced a large groundwater draw down and land subsidence, but currently it has solved these problems. The recover of the groundwater level went more smoothly than in Tokyo and it is because Lake Biwa and the Yodo River functioned effectively as an alternative water source. Furthermore, underground structures were constructed at relatively shallower depths compared to Tokyo area, so the problem of the floating power against the underground structures due to the recovery of the groundwater level hardly occurred at all. Recently Osaka has started the use of groundwater as a measure to reduce the heat island effect.

Absolute Gravity Field Measurements

Yoichi Fukuda (Kyoto University) ･ Jun Nishijima (Kyushu University)･
Takashi Hasegawa (Kyoto University)



To gain experience in making gravity measurements using the A10 absolute gravimeter and groundwater monitoring, we set up test sites in Osaka. Osaka is one of the most urbanized cities in Japan and built on soft sedimentary layers. Therefore, the conditions make it difficult to make gravity measurements. We established three gravity points in the eastern part of Osaka city and in Higashi-Osaka city where relatively large seasonal groundwater variations of a few meters are expected. The figure shows photographs taken at the gravity points.



Absolute gravity measurements were made three times in 2008 and 2009. The figure shows the gravity values recorded at the points. We repeated some of the measurements on the same day to confirm the repeatability. It is seen that the values recorded on the same day are within 10-20 mgals in spite of the noisy conditions.

The gravity changes may be caused by seasonal changes in the groundwater level.

Fukuda Y (2010): Report of the Gravity Group in 2009, in Urban Subsurface Environments, Newsletter vol. 9, RIHN, April 2010.

Recharge sources and flow system of groundwater

Shinji Nakaya（Shinshu University）・Jun Yasumoto（University of Ryukyus）

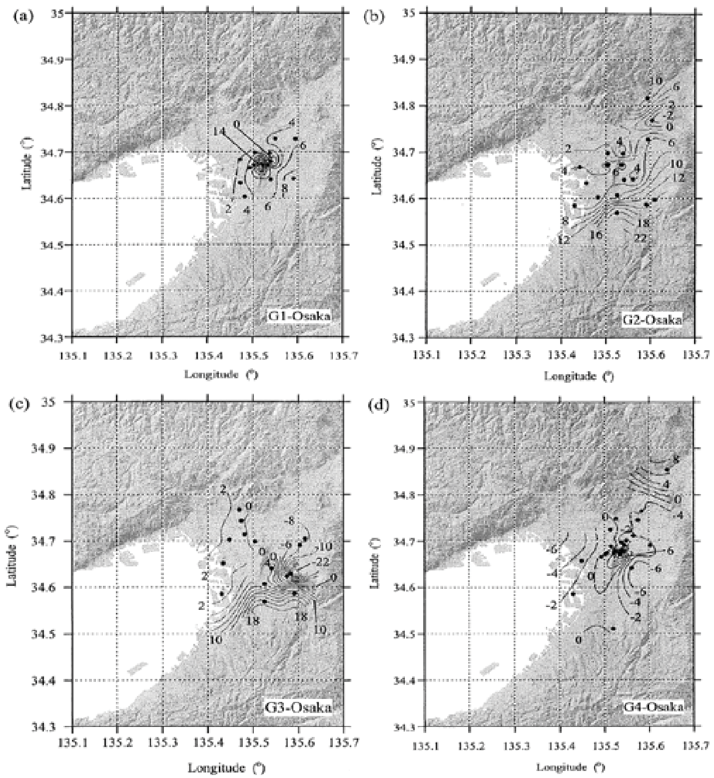


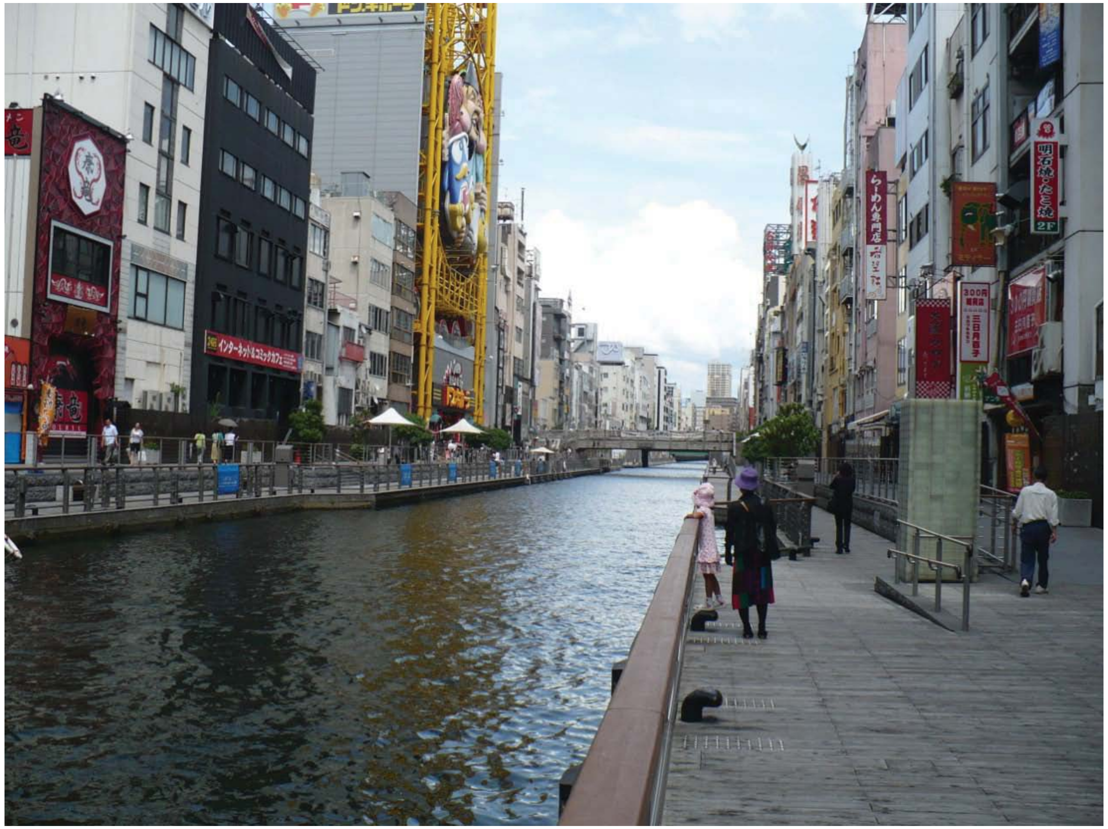
Fig. 1　Contour lines of groundwater table (Nakaya et al., 2009)

To determine the recharge sources and flow fields of the Osaka Basin groundwater tables, the spatial distributions of the stable isotopic ratios of oxygen, hydrogen, tritium concentrations, and major water chemicals were investigated. The stable isotopic ratios showed that groundwater was recharged at the Basin’s surrounding mountains, hills, and plateaus. The recharge ratio was estimated using the numerical simulation method.

S. Nakaya, M. Mitamura, H. Masuda, K. Uesugi, Y. Motodate, M. Kusakabe, T. Iida and K. Muraoka (2009)：
Recharge sources and flow system of groundwaters in Osaka Basin, estimated from environmental isotopes and water chemistry, *地下水学会誌*, 51(1), 15-41.

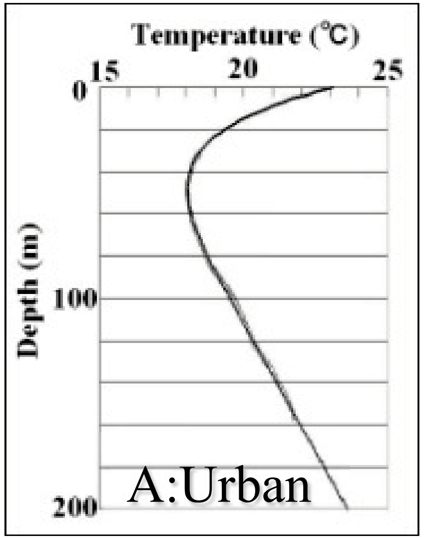
Subsurface Thermal Environment in Osaka

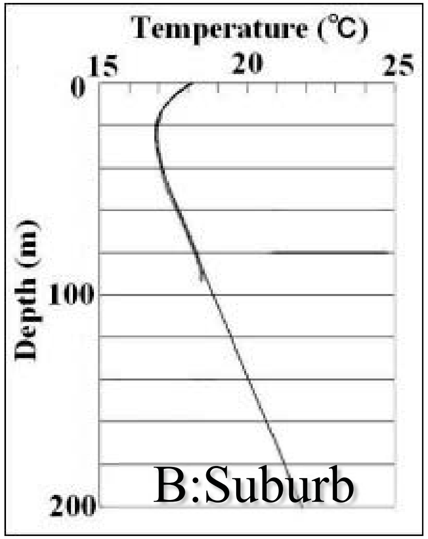
Due to the impact of the rapid temperature rise since about 1940, just as in Tokyo the reverse phenomenon is occurring: the temperature is higher at shallow locations than it is deep under the ground. This rise in the underground temperature is greater in the center of the City of Osaka than in the surrounding suburbs, showing that the heat island phenomenon arising from urbanization is having a strong impact on the subsurface temperature environment.

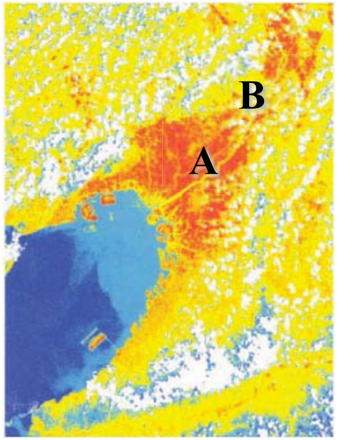


Subsurface warming

Makoto Taniguchi（RIHN）・Shaopeng Huang (University of Michigan) ・
Takeshi Uemura（Kaijo High school ）・Koichi Kitaoka（Okayama University）







Subsurface warming is evident in both urban and suburban Osaka. Groundwater temperatures are increasing due to global warming and the heat island effect from urbanization. Subsurface warming is greater in urban areas than in suburban areas.

Taniguchi, M. and T. Uemura (2005): Effects of urbanization and groundwater flow on the subsurface temperature in Osaka, Japan, Physics Earth Planetary Inter., 152, 305-313.
Huang, S., Taniguchi, M., Yamano, M., Wang, C. (2009): Detecting urbanization effects on surface and subsurface thermal environment -A case study of Osaka. Science of the Total Environment, 407(9):3142-3152.

Groundwater Pollution in Osaka

During the period of rapid economic growth in the 1960s there was a problem with volatile organic compounds (VOCs) but currently the figures are within the standards under the “environmental conservation goals,” partly due to the creation of regulations for environmental measures. However, the values for lead, nitrate-nitrogen, etc. are above their reference values.

The history of eutrophication recorded in a sediment core

Umezawa Y.（Nagasaki University）・Hosono T.(Kumamoto University)・
Onodera S.（Hiroshima University）

Figure 1. Osaka

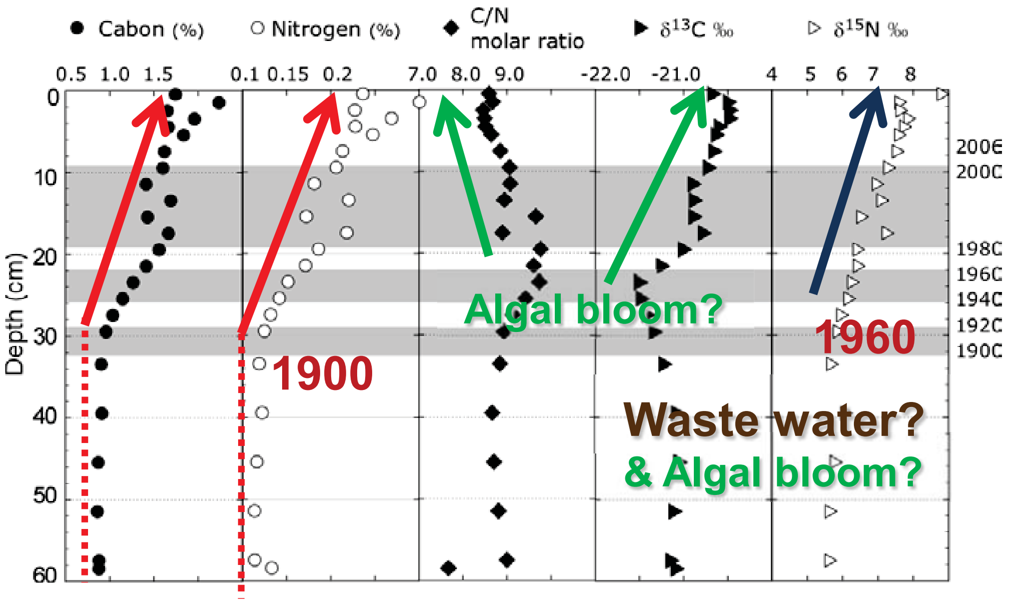
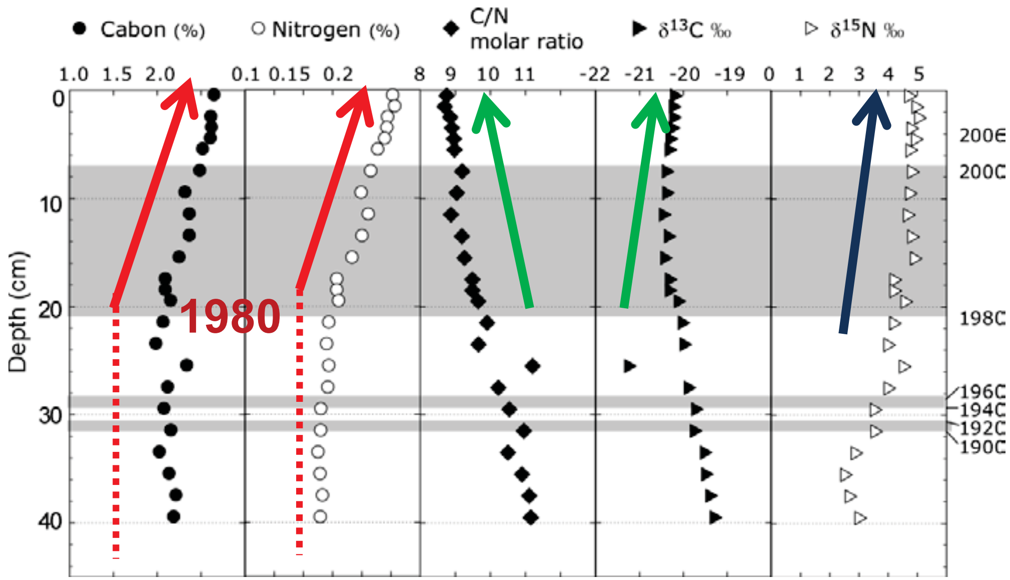


Figure 2. Manila



Carbon (C) and nitrogen (N) contents have continuously increased since 1900 in Osaka and since 1980 in Manila. On the other hand, the trends of the C/N ratio and δ^{13}C changed drastically around 1960 in Osaka, suggesting an algal bloom due to nitrification. Similarly, there was an increase in δ^{15}N probably due to the combination of a wastewater contribution as a nitrogen source and the effects of isotopic fractionation related to phytoplankton bloom under a hypereutrophic condition.

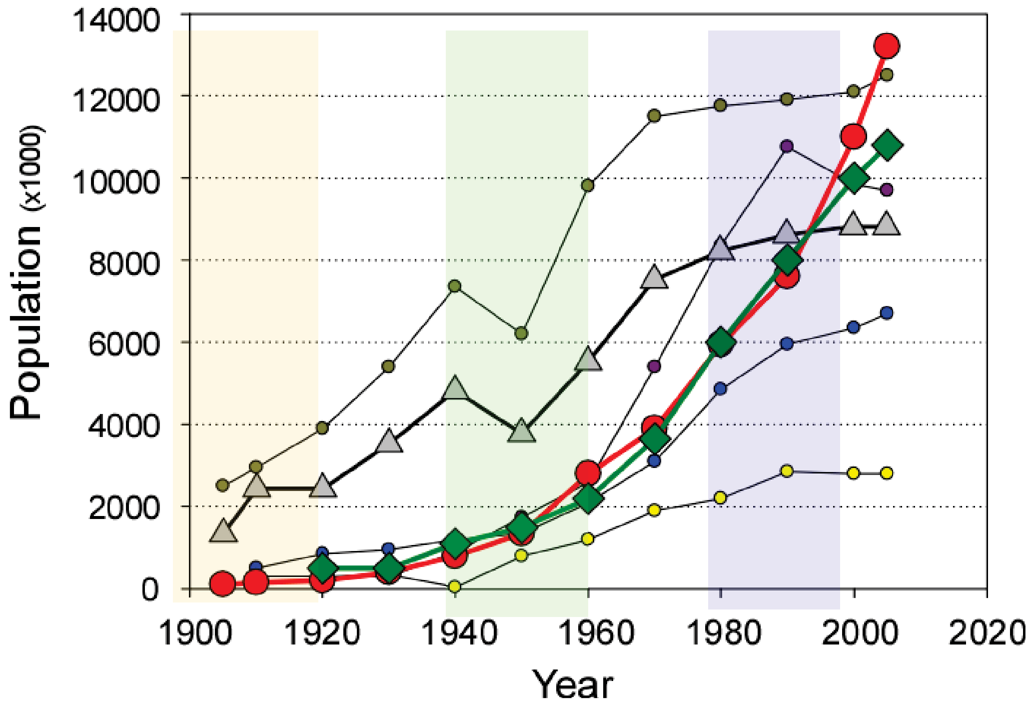
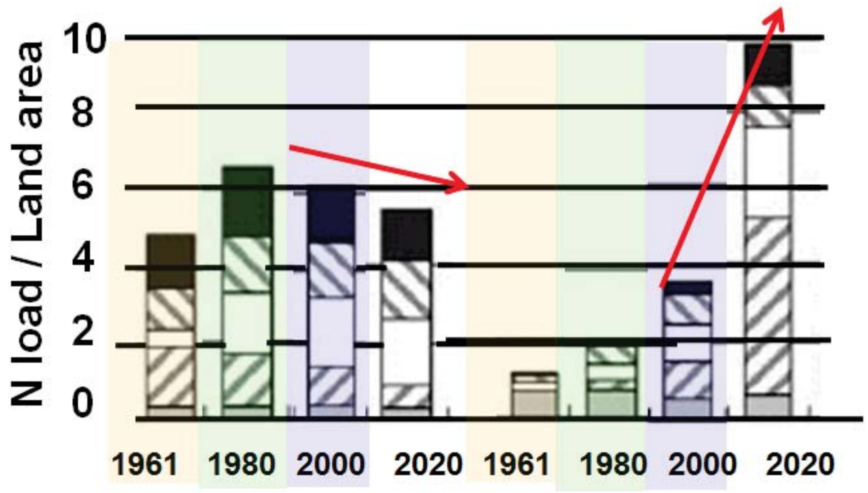


Figure 3
Time series of the population in Osaka, Manila and other cities



Shindo et al. (2006) Ecol Model

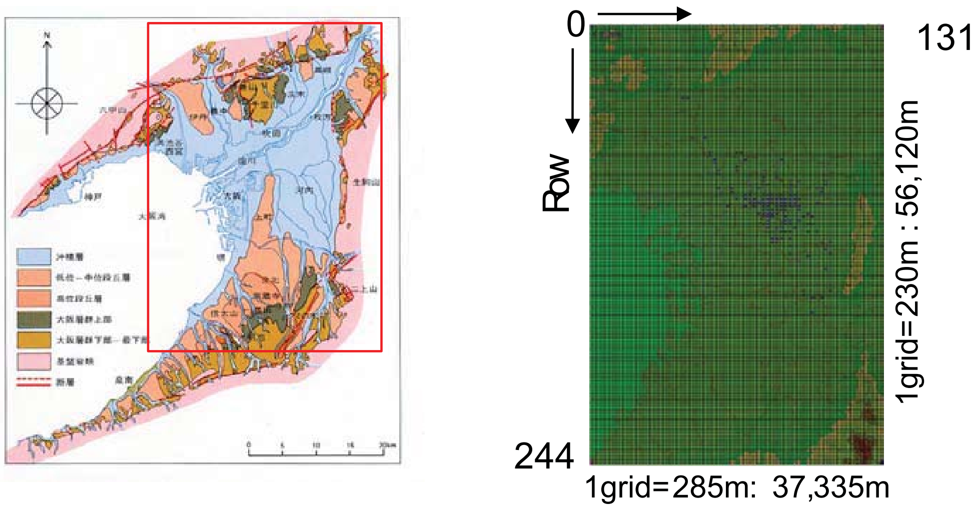
Figure 4. Estimated N loads with rapid economic growth in Osaka and Manila from 1961 to 2020

There has been an increase in population since 1900 in Osaka and since 1960 or 1980 in Manila and other mega-cities in South East Asia (Fig. 3). The population increases are reflected by N loadings. However, at a mature stage of urbanization, the loadings can be attenuated by advanced sewage treatment plant and dust removal systems (Fig. 4). The shift in N loadings corresponds with the trends of C and N profiles in the sediment core (Figs. 1 and 2).

Umezawa et al. “Carbon and Nitrogen Characteristics of Sedimentary Organic Matter as Indicators of Historical Trophic State in Osaka Bay, Jakarta Bay, and Manila Bay “ AOGS, Buasn, 2008.

Simulation of submarine groundwater discharge to Osaka Bay, Japan（Model, Rn)

Jun Yasumoto（University of the Ryukyus）・Yu Umezawa（Nagasaki University）・
Shinji Nakaya (Shinshu University)



The groundwater flow code MODFLOW-2000 (Harbaugh et al., 2000) is used in the simulation.

Figure 1. Model geometry and boundary conditions

As part of the extremely rapid urbanization of the Osaka Bay region, due to the postwar development of Japan's economy, the natural coastline was modified through the establishment of vertical engineering structures. Measuring SGD using a seepage meter is impossible in such an artificial coastal area. Therefore, the three-dimensional, regional-scale model shown in Fig. 1 was constructed to scale up local-scale studies to the entire bay. The groundwater flow code MODFLOW-2000 (Harbaugh et al., 2000) is used in the simulation.

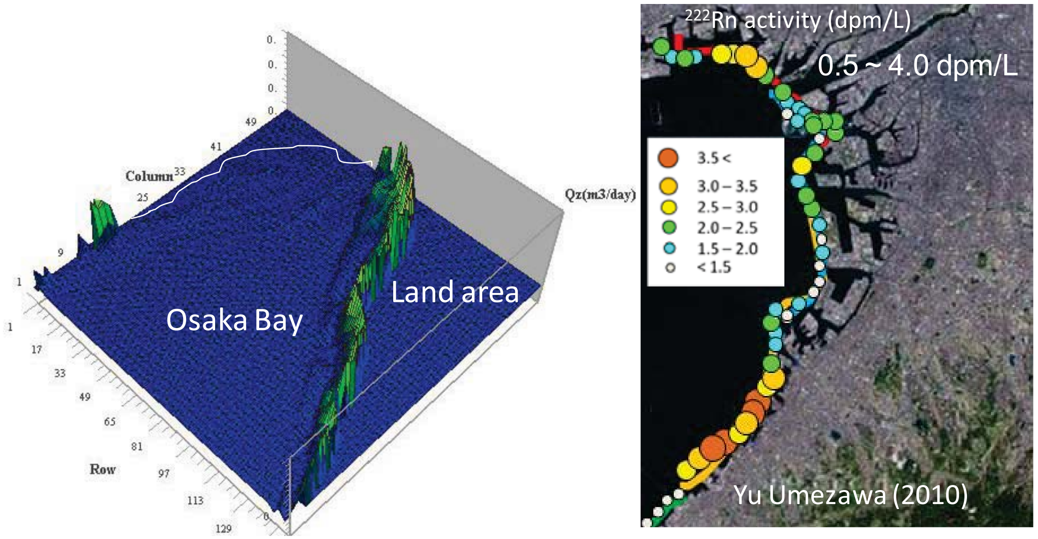


Fig. 2 Comparison of distributions of simulated SGD and observed ^{222}Rn activity

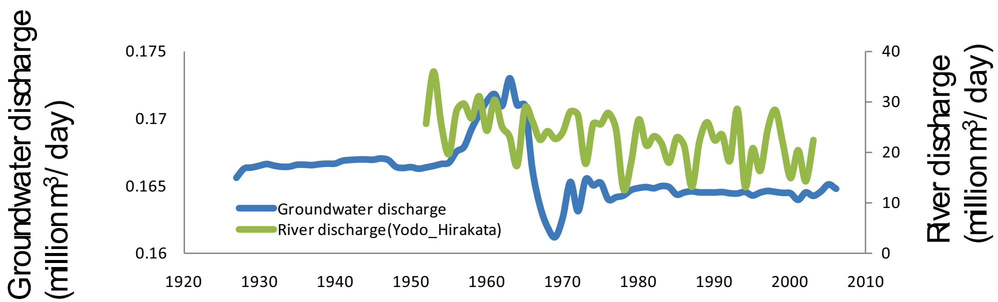


Figure 3. Simulated rates of fresh groundwater discharge compared with the measured rate of surface water discharge to Osaka Bay.

Figure 2 compares the distributions of simulated SGD and observed ^{222}Rn activity using RAD7 obtained by Yu Umezawa (2010).

Observed ^{222}Rn activity has a distribution similar to the simulated SGD distribution. However, in the area near the river mouth, ^{222}Rn activity is low even though simulated SGD is high.

In this area, it is possible that the SGD is interrupted by vertical engineering structures including landfills. The regional model does not include the effects of such vertical engineering structures. This is a cause of the difference between the observation and calculation.

Figure 3 shows simulated rates of fresh groundwater discharge compared with the measured rate of surface water discharge to Osaka Bay. The regional-scale simulation suggests that the average rate of fresh groundwater discharge to Osaka Bay for a period of 80 years (1925–2005) is about 9.3×10^6 cubic meters per day. Simulated groundwater discharge was compared with measured surface water discharge to the entire bay for a period of 50 years (1955–2005). For the same period, groundwater discharge to Osaka Bay was about 1% of surface water discharge.

Simulation of submarine groundwater discharge to Osaka Bay, Japan, Jun Yasumoto, Satoshi Nakada, Makoto Taniguchi, Shinji Nakaya, Yu Umezawa, Masahiro Takahashi & Shinaya Nakamura, Proceedings SWIM21 (Salt Water Intrusion Meeting), June 21-26, 2010.

Submarine groundwater discharge to Omaehama Beach in Osaka Bay, Japan

Satoshi Nakada(Kyoto University)・Jun Yasumoto（University of the Ryukyus）・
Makoto Taniguchi (RIHN)

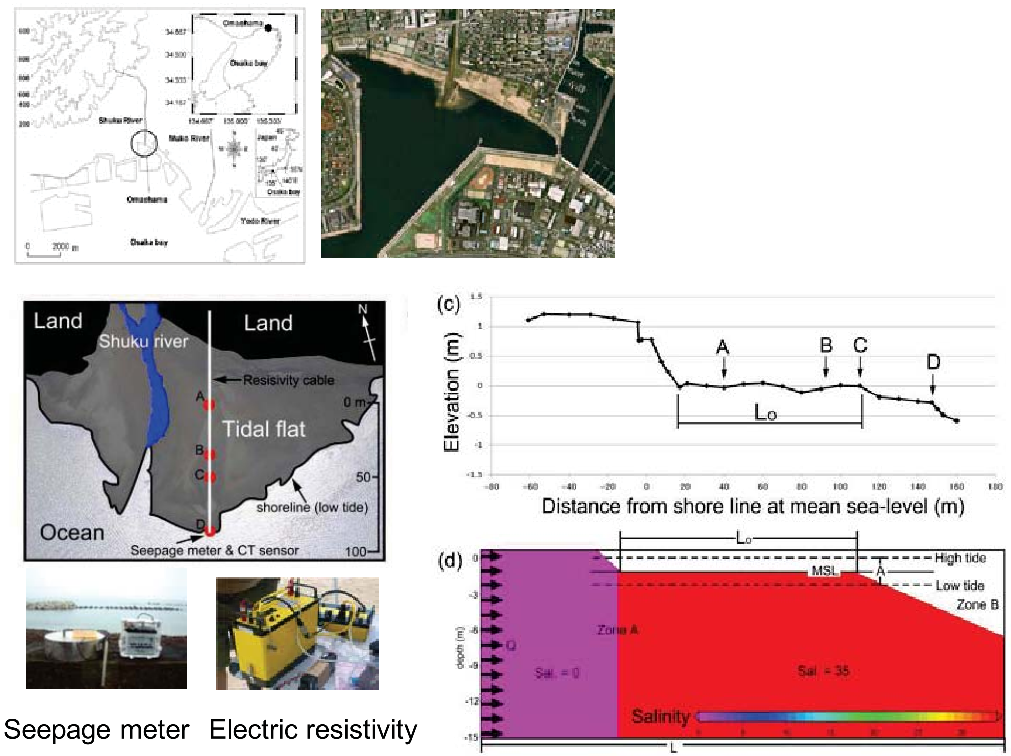


Fig. 1 A detailed cross-sectional model of submarine groundwater discharge

Coastal eutrophication from terrestrial nutrient discharge is a serious problem. This study focuses on the environmental rehabilitation of Osaka Bay, Japan, where eutrophication is occurring due to an increase in fertilizer and wastewater input through direct runoff and groundwater discharge from the residential, industrial and agricultural areas in the Osaka Bay catchment. However, groundwater discharge has not yet been quantified as the pathway of nutrient input in this area.

For the study of submarine groundwater discharge to Osaka Bay, a detailed cross-sectional model of submarine groundwater discharge has been developed to evaluate the field measurements using an automated seepage meter and conducting an electric resistivity survey on Omaehama beach, located in the northern part of Osaka Bay.

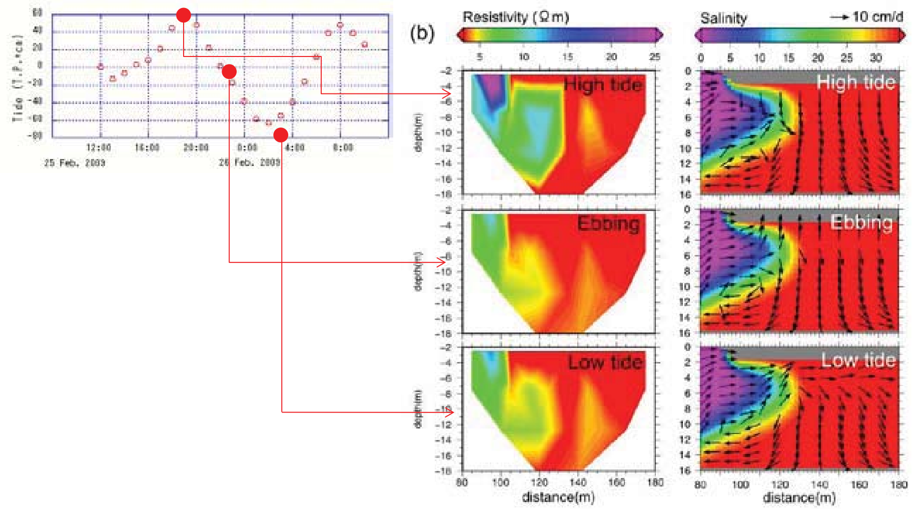


Fig. 2 Comparison of observed resistivity (Ωm) and simulated salinity

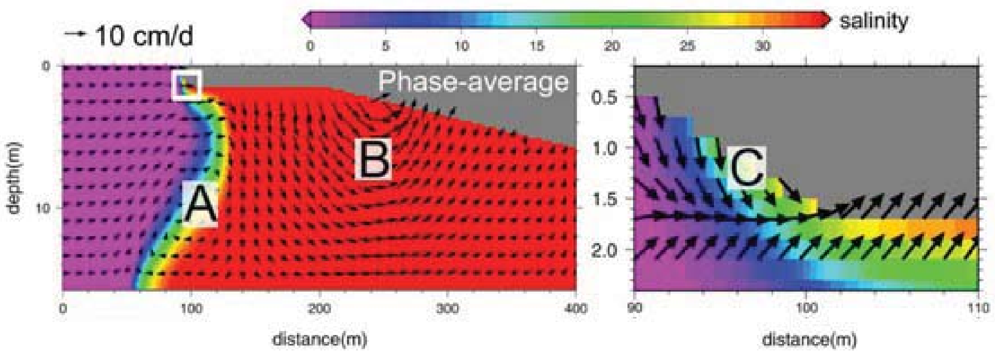


Fig. 3 Results obtained using the detailed cross-sectional model of SGD

Figure 2 compares the observed resistivity (Ωm) and simulated salinity in each tidal cycle. Observed resistivity reveals the existence of submarine groundwater. Observed resistivity varies more than simulated salinity. However, simulated salinity and observed resistivity have similar distributions.

Figure 3 shows the phase-averaged results obtained using a detailed cross-sectional model of SGD. Left panels show the phase-averaged vertical distributions of salinity (colors) and velocities of Darcy flux (arrows). The patterns of the submarine groundwater flow on the tidal flat at Omaehama beach show three circulations: (1) a small, upper seawater recirculation, (2) a deeper circulation across the interface between saltwater and freshwater, and (3) a large circulation on the offshore subterranean tidal flat and slope. The cross-sectional simulation suggests that the flow path where the fresh groundwater passed over the mixing zone between freshwater and seawater formed at low tide.

Simulation of submarine groundwater discharge to Osaka Bay, Japan, Jun Yasumoto et al, Proceedings SWIM21 , June 21-26, 2010. Submarine groundwater discharge and seawater circulation in an estuarine tidal flat, Satoshi NAKADA et al., Hydrological Processes (in press).