

Effects of urbanization, land-cover changes and groundwater flow on subsurface temperature in Japan

MAKOTO TANIGUCHI

Department of Earth Sciences, Nara University of Education, Nara 630-8528, Japan
e-mail: makoto@nara-edu.ac.jp

YASUO SAKURA

Department of Earth Sciences, Chiba University, Chiba 263-8522, Japan

YOHEI UCHIDA

Geological Survey of Japan, Tsukuba 305-8567, Japan

Abstract Inversions in temperature–depth profiles due to surface warming occur in big cities, such as Tokyo, Osaka, and Nagoya (Japan), and are attributed to urbanization, land-cover changes, and recent global warming. The surface warming extends deeper in the groundwater recharge area but is shallower in the discharge area. Thermal transport analyses, using heat conduction and convection under surface warming conditions, agree with values obtained from the water balance, hydraulic potentials, and tracer methods. The inversion due to surface warming may be a good tracer of the groundwater flow system.

Key words groundwater flow; land-cover change; subsurface temperature; urbanization

INTRODUCTION AND STUDY AREAS

Inversions in temperature–depth profiles due to surface warming occur in many areas of the world (Pollack *et al.*, 1998). The profile inversions are attributed to recent global warming, urbanization, and land-cover change. However, little attention has been directed towards understanding the effects of heat conduction and convection caused by groundwater flow on the temperature–depth profiles as affected by surface warming (Taniguchi *et al.*, 1999). The purpose of this study is to evaluate the effects of surface climate change and groundwater flow on the subsurface thermal regime of urbanized areas in Japan.

The study areas are Tokyo, Nagoya and Osaka, Japan. Groundwater temperature profiles were measured at 1–2 m depth intervals using a thermistor in 30 boreholes with depths ≤ 200 m in Tokyo, 41 boreholes with depths ≤ 280 m in Nagoya, and 15 boreholes with depths ≤ 300 m in Osaka.

EFFECTS OF URBANIZATION, LAND COVER CHANGES AND GLOBAL WARMING ON SUBSURFACE TEMPERATURE

Figure 1 shows long-term changes in air temperature in Tokyo, Nagoya, and Osaka. The annual increases in air temperature are 0.025°C, 0.015°C, and 0.020°C for Tokyo,

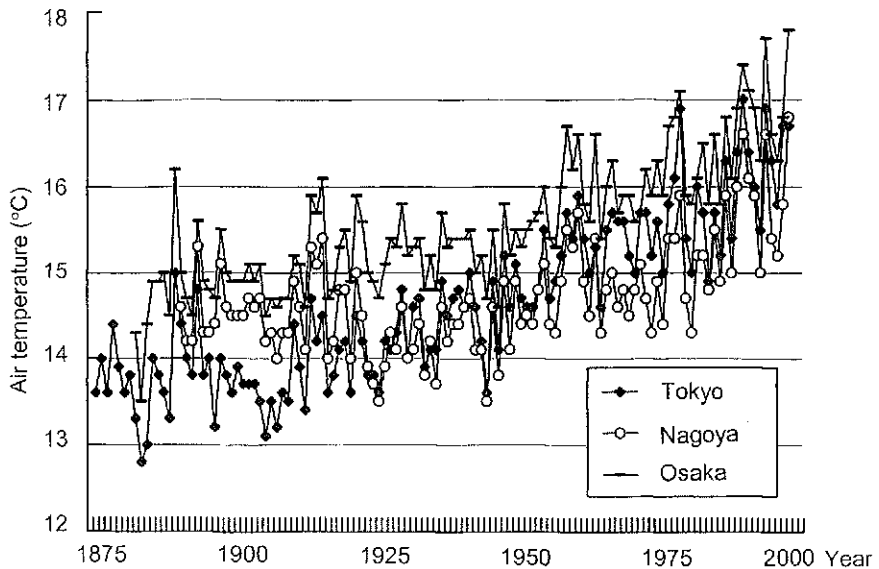


Fig. 1 Long-term changes in air temperature at Tokyo, Nagoya and Osaka, Japan.

Nagoya, and Osaka, respectively. According to global warming studies, the annual increase in air temperature is estimated to be less than 0.01°C . Therefore, the air temperature increases in Tokyo, Nagoya, and Osaka exceed the global warming estimates and the additional increase is attributed to urbanization and land-cover changes. In fact, inversions in groundwater temperature are not observed in many rural areas in Japan.

EFFECTS OF GROUNDWATER FLOW ON SUBSURFACE TEMPERATURE

The effect of surface warming on the subsurface thermal regime in the groundwater flow system varies regionally. The effect of surface warming due to urbanization and land-cover changes extends deeper in the groundwater recharge area but is shallower in the discharge area (Fig. 2). The depth of inversion due to surface warming indicates the magnitude of the vertical groundwater flux. Aquifer thermal transport was analysed using heat conduction and heat convection due to groundwater flow assuming the effect of surface warming to have a linear increase of $2.5^{\circ}\text{C } 100\text{-year}^{-1}$ in Tokyo, $1.5^{\circ}\text{C } 100\text{-year}^{-1}$ in Nagoya, and $2.0^{\circ}\text{C } 100\text{-year}^{-1}$ in Osaka. Estimations of groundwater recharge and discharge rates using the temperature–depth profiles agree well with the values obtained from water balance, hydraulic potentials, and tracer methods.

CONCLUSIONS

Inversions in temperature–depth profiles due to surface warming are found in subsurface thermal regimes in urbanized areas, such as Tokyo, Osaka, and Nagoya, Japan. Analyses using subsurface temperature profiles and heat conduction–convection

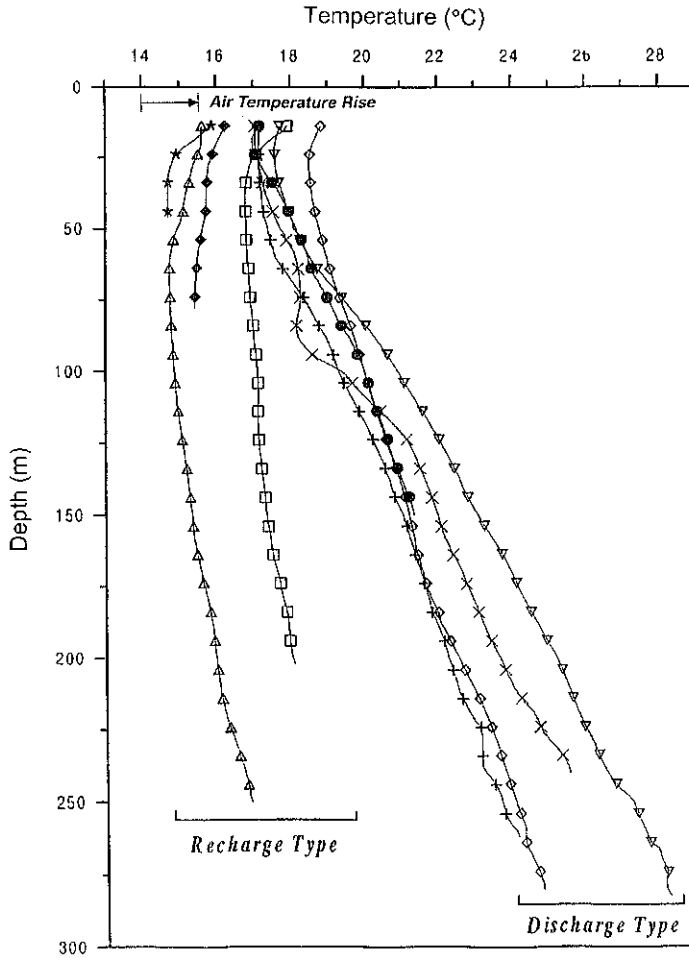


Fig. 2 Examples of observed temperature–depth profiles in Nagoya, Japan.

theory show that the inversions due to surface warming could be a good tracer of the groundwater flow system.

REFERENCES

- Pollack, H. N., Huang, S. & Shen, P. Y. (1998) Climate change record in subsurface temperatures: a global perspective. *Science* 282, 279–281.
- Taniguchi, M., Shimada, J., Tanaka, T., Kayane, I., Sakura, Y., Shimano, Y., Dapaah-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 the Tokyo metropolitan area, Japan. *Wat. Resour. Res.* 35, 1507–1517.