Land Subsidence and Subsurface Environmental Changes in The Tokyo Metropolitan Area, and Possible Groundwater Management for Urban Sustainability

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Abstract: The subsurface environments at the Tokyo Metropolitan Area have been changing in accordance with the change of groundwater condition and the continuous increase and heavy usage of underground space. Because of the complex interaction between the change of subsurface environments and human activities, we have experienced a variety of problems which have very often affected negatively to our society. This presentation describes the temporal changes of subsurface environments and associated problems at the Tokyo Metropolitan Area from 1920s until present. Then, the new techniques which are usable for strategic management of groundwater resources/subsurface environment are presented. Transferring Tokyo's experiences to presently developing and expanding urban cities into similar geological/hydrogeological settings is crucial to achieving sustainable developments of urban geosphere.

Keywords: ***Land subsidence, Tokyo, Groundwater management.***

Geology and Groundwater System in the Tokyo Metropolitan Area

Tokyo, the capital of Japan, is situated in the southwestern part of the Kanto plain, the largest plain in Japan. In Tokyo area, Late Pliocene and younger sediments and sedimentary rocks unconformably overlies the Miocene basement rocks. The shallower part of the sediments constitutes the confined aquifer-aquitard system. According to the Institute of Civil Engineering of Tokyo Metropolitan Government (1977), this confined aquifer-aquitard system is bounded at its bottom by relatively thick mudstone layer, and the top of this mudstone becomes shallower towards southwest. It is situated at more than 600 m depth in the northeast of Tokyo while it is about 100 m depth at the southwestern part of Tokyo. Below the aquifer bottom, the Plio-Pleistocene sedimentary rocks extend more than 2000 m thick, and it mainly consists of alternating sandstones and mudstones, which comprise a reservoir system of methane gas dissolved in water.

In addition to the above-mentioned confined aquifer system, there exists an unconfined aquifer in the area. Kawashima (2001) reported the temporal change of water level of unconfined aquifers and showed that the water levels are rather stable at least from 1970s to present.

Hazards Caused by the Significant Drop of Groundwater Potential

The well water levels of the confined aquifer had dropped to about 50 m below ground surface in the early 1970s. Because of the significant decline of the groundwater potential, severe land subsidence appeared as a direct result of over-exploitation of groundwater. Also, several confined aquifers had changed to become unconfined conditions and introduced the oxygen-deficient air mass under the ground. The oxygen-deficient air migrated along the aquifer and resulted in serious health damage to the people.

Regulation of Groundwater Use and Cessation of Land Subsidence

Because of the occurrence of the serious problems related to the over-extraction of groundwater, the local government and Japanese national government decided to regulate the groundwater extraction to the absolute minimum. From January 1961 until April 1974, the Japanese national government and the Tokyo Metropolitan government with its surrounding three prefecture governments implemented the following groundwater regulation laws. The national government has restricted groundwater withdrawal for industrial use since 1961 by the Industrial Water Law (in 1961, southern part of alluvial lowland was designated as a restricted area where no new wells were to be installed for industrial usage; in 1966, pumping of groundwater for industrial usage in southern part was restricted; in 1971, pumping of groundwater for industrial usage in the northern part was restricted), and for air conditional use since 1963 by the Law Controlling Pumping of Groundwater for Use in Building. In 1972, extraction of methane gas dissolved in water was suspended in the Tokyo area by means of purchase of the mining rights by Tokyo Metropolitan government.

After implementing the above-mentioned regulations, groundwater potential has recovered quickly, far better than expected. The rapid recovery of groundwater levels has been due to the relatively high recharge rate (2 to 3 mm per day) in this region (Shimada et al., 2002).

Problems of Underground Infrastructures due to the Recovery of Groundwater Potential

Even though the groundwater potential has recovered, it has caused new types of damage to the underground infrastructures which have been constructed during the drawdown period of groundwater potential in the region. The following shows an example of the problem.

Tokyo underground station was designed in 1965 and has been operated since 1972. At the time of its design, the groundwater level at the location was 35 m below the ground level, however, it has continuously recovered and reached to be 15 m below the ground level in 1998. The detailed investigation for the possible damage to the station revealed that the buoyant water pressure was quite high, and critical groundwater level for the severe damage was estimated to be 14.3 m below ground (Shimizu, 2004). The East Japan Railway Company decided to conduct countermeasure construction work to the station by applying ground anchor technique, which makes it possible to support the underground station until groundwater level be 12.8 m below ground (Kurasawa, 2001). Similar problems have been reported in Tokyo area (Ueno underground station (Kurasawa, 2001)) and in Osaka prefecture (Hashimoto, 2004). Hirose et al. (2004) summarized the published data on infrastructure damage caused by the recovery of groundwater level in Tokyo area.

Groundwater potential of confined aquifers has still been recovering in Tokyo area, and accurate prediction of the rate of recovery is necessary to plan the maintenance operations for the underground infrastructures.

Conclusions

This paper summarized the temporal changes of the subsurface environments and related challenges at the Tokyo Metropolitan Area. It is possible to divide the subsurface environmental changes in Tokyo into three stages, i.e., deterioration of subsurface environments due to over exploitation of groundwater (first stage), regulation of groundwater extraction to the absolute minimum and the recovery of groundwater potentials (second stage), and damaging underground infrastructures by buoyant force and increase of groundwater seepage due to the recovery of groundwater potentials (third stage). Transferring Tokyo's experiences to presently developing and expanding urban cities into similar geological/hydrogeological settings is crucial to achieve sustainable developments of urban geosphere.

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