AQUIFER WARMING ATTRIBUTED TO LAND-USE CHANGE IN JAPAN

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1. INTRODUCTION

Groundwater temperature is a key parameter regulating the ecological balance of groundwater dominated ecosystems. During periods of low-flow, groundwater discharges to surface water systems and maintains desirable thermal conditions for aquatic species. Urbanization effect has been identified as one of the main process of influencing aquifer thermal regime and has been dominated in altering subsurface temperature in Japan during 20th century (Taniguchi et al. 1999a). Therefore, the objective our study is to compare the magnitudes of ground surface and subsurface temperature that have changed under different climatic, geological and urbanization levels in three different study areas: the Sendai plain, the Kanto plain and the Chikushi plain in Japan.

2. STUDY AREAS AND DATA COLLECTIONS

Three study areas that we selected have different climatic conditions and have experienced with different level of urbanizations during the 20th century. According to the annual averaged surface air temperatures within last decade, Kanto (13.40°C) area has the highest temperature followed by Sendai (12.67°C) and Chikushi (11.76°C) areas. Moreover, all study areas show no significant warming trend until 1947. However, since 1947, surface air temperature has increased in a rate of 1.8-2.0°C/100 years. In contrast to temperature, annual total precipitations in these regions show no strong trend over the last 80 years.

Groundwater temperatures observed by the Geological Survey of Japan, AIST in 23 observation wells (10, 8 and 5 in Kanto, Sendai and Chikushi regions, respectively) in 2000 were used for the analysis. Moreover, one hour water level records in another six observation wells in Kanto region and four observation wells in the Sendai plain were collected. Time series analysis were performed and very high cross correlations (0.73-0.86) were found with no time delays for the water level fluctuations between different observation wells in all aquifer depths. However, strong correlations (0.5-0.73) were found with apparent time delays for water level fluctuations in same well point but in different aquifer depths. Time lag for the maximum correlation increased with the depth difference between aquifer depths. These estimations confirm that the groundwater recharge is dominant over horizontal water flow in these areas.

3. NUMERICAL MODELING

The U.S. Geological Survey's computer program VS2DH was used. The energy transport in the form of advection-dispersion equation can be written as:

$$\frac{\partial[\theta C_W + (1-\phi)C_S]T}{\partial t} = \nabla K_T(\theta)\nabla T + \nabla.\theta C_W D_H \nabla T - \nabla\theta C_W vT, \quad (1)$$

where t is time; θ is volumetric moisture content; C_W is heat capacity; ϕ is porosity; Cs is heat capacity of the dry solid; T is temperature; K_T is thermal conductivity of the water and solid matrix; D_H is hydrodynamic dispersion tensor; and v is water velocity.

The total domain depth was 150 m, where grid spacing varied from 0.1 m at the surface to 1 m at depth. All parameter values used were based on data from the Geological Survey of Japan and previous research (Uchida & Hayashi, 2005; Taniguchi et al. 1999a). For the initial boundary conditions, the temperatures at the bottom and the top of the porous medium were assigned by extrapolating the undisturbed linear portion of the temperature-depth (T-D) profile. According to meteorological records from 1927, surface air temperature started to warm rapidly in 1947 (**Fig. 1**). Therefore, 1947 was selected as the starting time for the model. The surface air temperature was used as a proxy and was filtered using a 5-year moving average for ground surface temperature (GST) estimation. Estimated ground surface temperatures showed less variation than surface air temperatures. The ground surface temperatures from 1947 to 2000 were first corrected to zero trends. The deviations in the estimated ground surface temperature from the averages from 1947 to 2000 were then added to the estimated initial ground surface temperature at each well location to incorporate the ground surface temperature change over time at each well point. To incorporate the different warming rates attributed to different level of urbanizations, various warming rates were then added to ground surface temperature series (3°C/100 years as in **Fig. 1**). The warming rate and groundwater recharge were used for model calibrations.

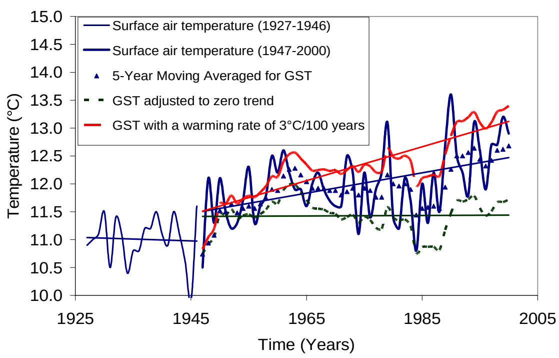

Fig. 1 Approximated warming rates for Sendai region

4. RESULTS AND DISCUSSION

Fig. 2 shows the observed and simulated T-D profiles and **Table 1** depicts the calibrated rates of ground surface warming and the magnitude of ground surface warming estimated in all three regions. Background temperature in the aquifer is higher than the annual

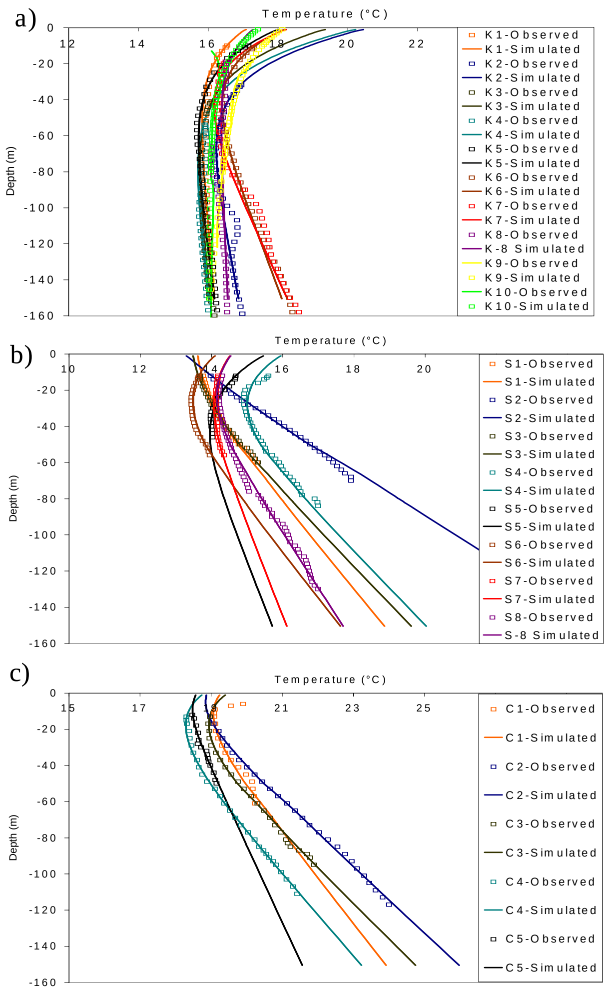

Fig. 2 Observed and simulated temperature-depth profiles; a) Kanto, b) Sendai and c) Chikushi region.

Table 1 Ground surface warming over 60 years

Study area	Rate of ground surface warming (°C/100 years)	Ground surface temperature change over 60 years (°C)
Kanto	2.0 - 9.5	1.1 – 5.2
Sendai	0.8 - 6.5	0.6 – 3.3
Chikushi	0.4 - 4.0	0.5 – 2.4

average air temperature, giving an upward heat flow from the interior of the earth. In the absence of convective effect, this produces a linear geothermal gradient within homogeneous depth intervals in the depths have no seasonal variations. In the presence of groundwater recharge (or discharge), geothermal gradient is perturbed by the infiltrating cool water (or upward flow of warm water in discharge areas), resulting concave T-D profile (or convex profile in discharge areas, e.g. Taniguchi et al. 1999a). According to the observed hydraulic gradients in different aquifer depths, observation wells are located in recharge areas, where we can expect shallow subsurface layers with lower temperature than what should have produced by general geothermal gradient (concave upward profiles). However, in all wells, there is clear evidence of aquifer warming, which is higher than resulting temperature due to natural geothermal gradient in all depths. The magnitude of ground surface warming, which was calculated as the difference between the simulated subsurface temperature profile and the extrapolated steady state linear curve to the ground surface, ranges in different magnitudes (0.5-5.2°C near ground surface as in **Table 1**) giving the highest warming in Kanto region followed by Sendai and Chikushi regions. Many researchers analyzed global trends in air temperature change and found a 0.5–0.7ºC/100 years warming rate during the 20th century. In our study areas, ground surface warming rate is significantly higher than the averaged global warming trend and also there is clear difference in ground surface warming between rural and urban areas. This difference is as high as 4.1ºC in Kanto region, where the commercial capital of Japan (Tokyo) is located. Therefore, it is confirmed that urbanization effect has been dominated the causes of changing aquifer temperatures in Japan in 20th century.

5. CONCLUSIONS

Since last two decades, there are many attempts to mitigate the thermal impact attributed to anthropogenic forces (e.g. removing a culvert and restoration of groundwater discharge to regulate stream temperature in a highly urban setting). These studies often assigned groundwater a constant temperature, which due to urbanization effect can significantly vary. In this study, we found significant ground surface warming rates attributed to rapid urbanization in 20th century in Japan. The estimated warming rates are substantially larger than the average global warming rate and also evidence of ground surface warming is as higher as 4.1ºC in urban areas than their rural surroundings. Model estimations that suggest decreasing stream temperature can therefore bring project failures due to aquifer warming. The results of our study have therefore implied the importance of considering urbanization impact (and potential climate change variations) on aquifer thermal regime in habitat restoration programs.

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