Changes in deep groundwater level in an unconfined aquifer by barometric pressure and earth tides in the southern Beppu, Japan

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Ocean and earth tides and barometric pressure affect changes in groundwater levels in confined aquifers, but not unconfined aquifers. Deep groundwater level (i.e. thick unsaturation zone) in an unconfined aquifer, however, is influenced by changes in the barometric pressure because the difference of the levels between the observation well and the aquifer occurs. The deep groundwater levels in the unconfined aquifer at the two observation wells located in the IGS, Kyoto University, Beppu city were observed from 19 August 2017 to 23 July 2018 with one hour interval. We revealed factors affecting the periodic variations of the groundwater levels using the Fourier transform and cross correlation analysis and verified the effects of the earth tides by calculating amplitude of four tidal components (O_1, K_1, M_2, S_2) using BAYTAP-G software.

Observation wells, OW1 and OW2, are 1.8 km from the Beppu bay. The elevations of the wells are 80 m and 73 m above sea level (a.s.l.), respectively and the groundwater levels were observed in range of 39 m to 44 m (a.s.l.) during the observed period. In general, the groundwater level in the unconfined aquifer is found in few meters below the surface, but that of the observations wells in the study were measured at about 30 m below the surface. Amplitude spectra of the groundwater levels and the barometric pressure calculated by the Fourier transform showed significant spectra at K_1 and S_2 components and eight-hour period, indicating that the barometric pressure affects the changes in the groundwater levels in the wells. Maximum cross correlation coefficient of the groundwater levels showed negative values, reflecting the inverse relationship with the barometric pressure and the cross correlation coefficient of well OW2 was higher than that of well OW1. Time lags of the groundwater levels against the barometer had one hour and zero hour at well OW1 and OW2, respectively. This means that barometric pressure affects more easily well OW2 than OW1.

Amplitude of the tidal components calculated by BAYTAP-G software showed that O_1 is 0.3 and 0.7 mm, K_1 is 2.2 and 9.0 mm, M_2 is 0.5 and 0.6 mm, and S_2 is 0.7 and 2.0 mm at well OW1 and OW2, respectively. The amplitude is high at the K_1 and S_2 components same as the Fourier transform’ s result. The changes in the groundwater level (dh) in the unconfined aquifer by the earth tides are related to changes in the volumetric strain (ds), porosity (n), and the aquifer thickness (b). If parameters set that b, n, and ds are 50 m, 0.3, and 10^{-8}, respectively, the dh is 0.017 mm using the following formula: dh =-(ds/n)b. The changes in the observed groundwater levels by tidal components are higher than that by the theoretical one. It reflects that the earth tides affect the groundwater level oscillation that is hidden by the effects of the barometric pressure in this area.

Keywords: Barometric pressure, Earth tide, Groundwater level, Unconfined aquifer, Volumetric strain

