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Regional mapping of vertical hydraulic gradient in urbanized alluvial fan: the case study of the Toyohira alluvial fan

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1. Introduction

An alluvial fan is representative of three-dimensional flow systems of groundwater owing to topographical, hydrological, and hydrogeological factors. As often seen in Japan and around the world, its groundwater flow system becomes more complex as a result of excessive withdrawal and numerous understructures. Areal information on vertical groundwater flows is no less critical than horizontal flows for interpreting actual 3D groundwater flow systems. The purpose of this study is to propose a quasi-3D approach: mapping vertical hydraulic gradient (VHG) based on groundwater table elevation (GTE).

2. Materials and methods

The regional mapping is constructed in the Toyohira alluvial fan, Sapporo, Japan. Over one thousand of well data in the site are gleaned from the publications and website of public agencies and private companies. First, a filtering process in the well data is performed because uncertainty generally arises from differing measurement times. Annual mean variations and daily fluctuations of water level in 30 observation wells are shown, and a nonparametric trend analysis is also performed. Next, the extracted water levels obtained since 1988 are divided into two categories: shallow wells of up to 20 m deep (n = 216), and deep wells of greater than 20 m deep (n = 203). The dataset is input into a geographical information system with geostatistical interpolation procedure. A GTE map of shallow well data is generated as topographic drift added to residuals interpolated by ordinary kriging. Then, each individual VHG value of the deep wells is calculated from its water level and estimated GTE at the location, and a VHG map is interpolated by moving neighborhood kriging. It is often hesitating in VHG calculation whether screen depths of deep wells are used for VHG calculation. For addressing the uncertainty, three cases, i.e., the top, middle, and bottom elevations of the screen depths, are used for VHG mapping, and cross-validation is applied to determine most reasonable VHG map.

3. Results and discussion

The annual water variations show that dewatering by the subway construction occurs before 1988, but thereafter daily fluctuations statistically range within a few meters. Also positive trends are seen in an area of the distal part, and negative trends in an area of the apex. Positive trends likely indicate a change of water intake, while negative trends indicate decreasing total water storage in the fan. The resulting GTE map shows that a GTE mound appears the focused recharge zone along the river. The groundwater table in the center of the city is about 5 m deeper than the previous table before subway construction. Cross-validation shows adequacy of the VHG map of the bottom screen depths. The VHG map better visualizes that downward flows of groundwater are predominant over the fan, owing to a basement depression at the head, seepage loss from the river in the middle, and artificial dewatering in the distal part.

Keywords: alluvial fan, groundwater, trend analysis, kriging, hydraulic gradient, urbanization