Investigating hydrological drivers of a deep-seated gravitational slope deformation – the Vögelsberg case study (Tyrol, Austria)

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Abstract

This contribution presents preliminary results on investigating and assessing hydrological drivers forcing temporally varying movements of a deep-seated landslide. Time series correlations of area-wide simulated hydro-meteorological water, groundwater level and slope displacement rate combined with preliminary hydrological monitoring results including stable isotope analyses of groundwater and precipitation deepen the understanding of the landslide's hydrological triggering mechanisms and their spatio-temporal characteristics.

Introduction

Deep-seated gravitational slope deformations (DSGSD) can have considerable impacts on settlements in mountainous areas. Constant deformation of Earth's surface causes damage on superimposed houses and other infrastructure leading to uninhabitability. DSGSDs are commonly complex systems of various interacting slabs showing differential movements in the order of a few millimetres up to several centimetres per year. Spatio-temporal patterns of movement are typically controlled by changes in the aquifer's pore water pressure which reduces the shear strength. Knowing the mechanisms causing temporal pore-water pressure variations is therefore essential for deploying target-oriented measures aiming to reduce hydrologically driven deep-seated landslides.

This contribution presents investigations of the hydrological drivers forcing temporally varying movements of an active slab of the Vögelsberg DSGSD in the lower Watten valley (Tyrol, Austria). The overall aim of this study is to deepen the understanding of how the landslide reacts to hydro-meteorological changes by comparing continuous displacement time series with preliminary results of both, hydrological monitoring and modelling. This includes (i) constraining the mean elevation of the recharge area of the landslide's aquifer based on stable isotope data, (ii) reconstructing potential groundwater flow paths, and (iii) exploiting spatio-temporal data of parameters essential for groundwater recharge (e.g. snowmelt and rainfall).

Study Area

The Vögelsberg landslide is an actively creeping deep-seated landslide situated on the toe of a complex deep-seated gravitational slope deformation. The landslide body is sparsely settled, where buildings suffer from differential slope movements. Borehole explorations depict (i) a shear zone located in 48 m below surface, (ii) a piezometric head between -6 and -8.5 m below the surface and (iii) heavily disaggregated quartzphyllite components in a matrix-rich environment dominated by sand, silt and clay grain sizes up to bedrock contact at 70 m below surface.

Methods

Slope displacements are quantified at certain points on an hourly basis by an automated tracking total station (ATTS) operating since 2016/05. A comprehensive hydrological monitoring consisting of measurements of discharge, electrical conductivity, temperature and stable isotopes of water emerging at springs and sampled in two groundwater wells is combined with field mapping and precipitation sampling at elevations between 880 m and 1980 m a.s.l. (Figure 1). The hydroclimatological model AMUNDSEN is used for a spatio-temporal assessment of potential groundwater recharge by simulating rainfall, melt water derived from snow cover and evapotranspiration.

Results

Preliminary results indicate a significant correlation between groundwater level and landslide velocity. Delayed increases in pore water pressure accompanied by an acceleration of the landslide movement are associated with hydrometeorological events such as prolonged rainfall, snowmelt or the combination of both. Analyses of the simulated spatio-temporal dynamics of snowmelt within the landslide catchment have shown that during the late winter and spring of 2019 snow melt above 1700 m a.s.l. occurred after the landslide's acceleration. This observation indicates that for this acceleration event groundwater recharge was mainly driven by snow melt below this elevation.

The mean groundwater recharge elevation of springs was assessed based on oxygen isotope data using a δ18O gradient of -0.18 ‰ per 100 m. Results suggest that water emerging at springs near the landslide infiltrates between 1240 m and 1650 m a.s.l. Spatial distribution of δ18O values and electrical conductivity values of the sampled springs, indicate that water emerging at lower elevation must have recharge areas at higher elevation compared to water emerging at mid-slope. This finding suggests the existence of at least one coherent aquifer close to the surface. The synthesis of monitoring and modelling data combined with field mapping allows to derive a conceptual slope model identifying major hydrological processes involved in controlling the landslide's deformation behaviour.

Ongoing precipitation sampling and stable isotope analyses will improve the conceptual hydrogeological model. The construction of a local δ18O-elevation gradient for precipitation, after completing the measurements covering one year, will allow localising aquifer recharging areas more precisely. A solid conceptual hydrogeological slope model will allow water balance calculations and numerical groundwater modelling for investigating potential measures aiming at lowering the groundwater level.

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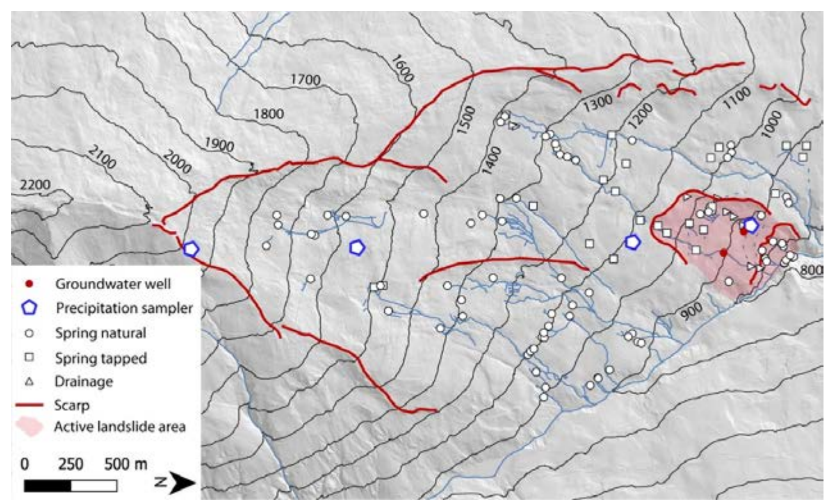

Figure 1 Map showing the hydrological monitoring setup of the Vögelsberg DSGSD.