Artificial recharge in heterogeneous aquifers: impact of bedrock interface geometry on recharge dynamics

Nicolas M., OSUR Géosciences Rennes, UMR6118 CNRS – Université de Rennes 1; BRGM D3E, New Resource & Economy Unit, Indo-French Center for Groundwater Research
Selles A., BRGM D3E, New Resource & Economy Unit, Indo-French Center for Groundwater Research
Bour O., OSUR Géosciences Rennes, UMR6118 CNRS – Université de Rennes 1
Maréchal J.C., BRGM, D3E, New Resource & Economy Unit
Dewandel B. BRGM, D3E, New Resource & Economy Unit
Bailly-Comte V., BRGM, D3E, New Resource & Economy Unit
Ahmed S., National Geophysical Research, Institute Indo-French Center for Groundwater Research

Key words: MAR, fractured crystalline aquifers, heterogeneous structure, numerical modelling, analytical modelling

In the face of increasing demands for irrigated agriculture, many states in India are facing water scarcity issues, leading to severe groundwater depletion. In this context, the Indian government has set out to remediate water scarcity issues through the development of large scale managed aquifer recharge (MAR) schemes. However, perennial water resources in southern India consist mainly of crystalline aquifers, which are characterized by their structural heterogeneity and associated complex flow dynamics. Many studies have highlighted the crucial role played by preferential flow pathways, most notably the interface between the upper weathered layer and the underlying fissured bedrock, which is the most transmissive portion of the profile. However, these pathways have most often been considered to be sub-horizontal, which neglects possible effects of this pathway's geometry (i.e. its topography) on aquifer connectivity and flow. Thus, the focus of this study is to investigate the effect of basement topography on artificial recharge. To do so, we analysed infiltration and drawup dynamics resulting from the implementation of a MAR structure, i.e. an infiltration basin. This structure was set up in the Experimental Hydrogeological Park in Telangana (Southern India), a well-equipped and continuously monitored site, and it is periodically supplied with surface water deviated from the nearby Musi river, downstream of Hyderabad.

Monitoring of water levels in the basin and collection of rainfall and evaporation data allowed us to perform an initial volume balance equation. We thus quantified the inputs from the MAR structure into the groundwater system. Further, variations in the recession slope of basin water levels were used as a proxy to estimate percolation efficiency variations. Finally, groundwater levels were monitored in 11 onsite boreholes and were used to calibrate analytical and numerical simulations of recharge processes. Analytical modelling was aimed at obtaining a first order estimation of controlling parameters. Numerical modelling was used to test the effect of aquifer geometry on water level drawup dynamics. The numerical simulations consisted of an unconfined aquifer overlain by a thick unsaturated zone recharged by a basin. Two scenarios were tested, the first one assumed a homogeneous aquifer with sub-horizontal geometry. The second contained a cuboid depression at the centre of the aquifer, where the length and height were varied to constrain the effect of aquifer geometry heterogeneity on drawup dynamics.

The first observation made was the non-linearity of groundwater recharge, as the relationship between basin infiltration and groundwater level increase varied in time, as well as percolation efficiency. Then, hydraulic parameters obtained through analytical modelling calibration pointed towards a dominant role of preferential flow paths, with high permeability and storage coefficients, which has moreover often been observed in fractured crystalline environments [1,2]. Numerical modelling highlighted our inability to reproduce the observed groundwater data assuming a sub-horizontal disposition of the basement. On the other hand, the model containing the depression (and therefore boundary conditions changing with depth) was much closer to reality. The lateral extension of the depression controlled the slope of the drawup, where smaller compartments led to stronger drawup slopes. The vertical extension of the depression had an impact on the amplitude of variations but not on the slope. In this way, we were able not only to improve our numerical simulations' accuracy, but to loosely constrain the dimensions of the topographic depression describing the geometry of the bedrock interface. Overall, fractured crystalline aquifer mechanisms on the site seemed best described when considering the existence of a compartment of limited lateral extension. This observation is supported by imaging of the depth of the weathered layer using ERT, which shows hilly basement topography, composed of depressions and crests, where crests delineate a set of sub-drainage basins (Fig. 1). It is also supported by previous studies in south

Indian granitic terrain [3,4], which have linked the non-linear behaviour of hard rock aquifers to aquifer compartmentalization: depending on piezometric levels, the different "compartments" (i.e. well-connected zones of limited lateral extension) may become connected and cause a transition from local to regional flow conditions [3]. Thus, our study shows promising results regarding improved simulations and understanding of the effect of basement topography on flow and recharge processes, and even possible quantification of aquifer geometry through monitoring of groundwater levels only.

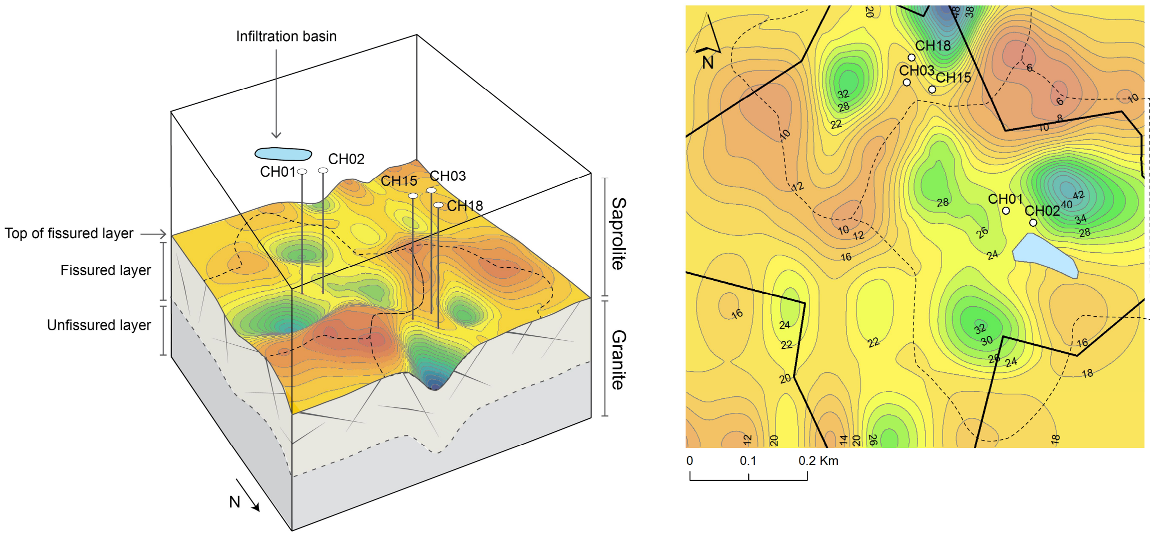

Figure 1: Topography of the transmissive bedrock interface interpreted from Electrical Resistivity Tomography profiles

[1] T. Gleeson, K. Novakowski & K.T. Kyser. Extremely rapid and localized recharge to a fractured rock aquifer. *J. Hydrol.*, **376(3–4)**, 496–509, (2009).

[2] B. S. Sukhija, D. V. Reddy, P. Nagabhushanam & S. Hussain. Recharge processes: piston flow vs preferential flow in semi-arid aquifers of India, *Hydrogeol. J.*, **11(3)**, 387–395, (2003).

[3] N. Guihéneuf, A. Boisson, O. Bour, B. Dewandel, J. Perrin, A. Dausse, M. Viossanges, S. Chandra, S. Ahmed & J.C. Maréchal. Groundwater flows in weathered crystalline rocks: Impact of piezometric variations and depth-dependent fracture connectivity. *J. Hydrol.*, **511**, 320–334, (2014).

[4] A. Boisson, N. Guihéneuf, J. Perrin, O. Bour, B. Dewandel , A. Dausse, M. Viossanges, S. Ahmed & J.C. Maréchal. Determining the vertical evolution of hydrodynamic parameters in weathered and fractured south Indian crystalline-rock aquifers: insights from a study on an instrumented site, *Hydrogeol. J.*, **23(4)**, 757–773. (2015).