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► To cite this version:

Madeleine Nicolas, Benoît Dewandel, Jean-Christophe Maréchal, Mizan A, Adrien Selles, et al.. Natural recharge heterogeneity at the catchment scale, in fractured crystalline rock aquifers. AGU Fall Meeting 2018, Dec 2018, Washington, United States. . hal-03402066

HAL Id: hal-03402066

<https://brgm.hal.science/hal-03402066>

Submitted on 25 Oct 2021

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Natural recharge heterogeneity at the catchment scale, in fractured crystalline rock aquifers

Case study in semi-arid Southern India

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Straightforward estimation of GW recharge at large scales is possible using Water Table Fluctuation methods. However, separating, quantifying and localizing contributions from different recharge processes (diffuse vs. localized) is more difficult, yet crucial in (semi-)arid climates where water stresses and GW overexploitation threaten the livelihoods of those who depend on it.

Abstract ID: 406686

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1. INTRODUCTION AND CONTEXT

Regional scale

Geology & Climate

- Preponderance of igneous rock
 - Low yields
 - Intrinsic heterogeneity and complexity
 - Often only perennial source of freshwater
- Semi-arid climate

Study site

Maheshwaram catchment

- Rural socio-economy
 - Dominance of rice
 - Highly pumped
- Large amount of data
 - Well known properties (soil type & distribution, hydrodynamic)
 - Long term WL monitoring
 - Seasonal WL campaigns

3. METHODOLOGY 5. RESULTS

Model overview

Pseudo 2D hydraulic model

Model inputs

Gridded data from literature & database

- Soil Type → Soil hydraulic properties
 - Alfisols 1
 - Alfisols 2
 - Entisols
 - Inceptisols
 - Tank
- Land Use & Land Cover → Inputs from irrigation and RET
 - Forest
 - Fruit
 - Paddy (Seasonal)
 - Paddy (Yearly)
 - Scrub
 - Tank
 - Urban

Unsaturated eqs.

- $h_t(\theta) = h_{BC} \times \left(\frac{\theta_s}{\theta_t}\right)^{\frac{1}{\lambda}}$
- $K_t(\theta) = K_S \times \left(\frac{\theta_t}{\theta_s}\right)^\eta$
- $q_t = -K(\theta)\left(\frac{dh}{L} - 1\right)$

Saturated eqs.

- $h = Inputs(t) - RET_t - (\theta_s - \theta_{t-1}) \times L$
- K_S
- $q = -K_S\left(\frac{dh}{L} - 1\right)$

see Dewandel et al. (2006) & de Condappa (2005)

2. A COMPREHENSIVE MEASURE OF RECHARGE

Reference values in space

→ Heterogeneous yet recurring recharge patterns

Water Table Fluctuation (WTF) method

$$R + RF + Q_{gn} = E + PG + Q_{df} + S_y \Delta h$$

- + Easy and low cost application
- + Relatively accurate estimates
- Accuracy depends on accuracy of S_y and Δh
- Integrates both *diffuse* and *focused* recharge

see Maréchal et al. (2006)

Recharge relative to total rainfall

→ Linear relationship between yearly rainfall and yearly recharge

→ Raw results

→ Upscaled results

- Paddy fields act as zones of enhanced diffuse recharge
- Silty soils in drainage network are antagonistic to diffuse recharge

Outputs (mm)		Inputs (mm)		
Diff. rech.	Runoff	RET	Rainf.	Irrig.
92	107	725	845	121

- Indirect and localized processes allow for recharge when mean soil moisture is too low

Recharge patterns

Focused recharge (mm/yr) = Total rech. - Diffuse rech.

- Strong correlation to topography
- Despite the non-receptiveness of silty soils, drainage network zones are zones of focused recharge

4. MODEL SENSITIVITY

Sensitivity Analysis

Determine effect of parameter uncertainty on recharge

$$S_{i,t} = P_i \frac{O(P_i + \Delta P_i) - O(P_i)}{\Delta P_i}$$

- $S_{i,t}$: Normalized sensitivity of the i^{th} input parameter at time t
- O : Output function of the system
- P_i : i^{th} input parameter

- θ_s : Volumetric moisture content at saturation [m^3/m^3]
- η : Texture dependent retention shape parameter [-]
- L : Soil thickness [m]
- K_S : Hydraulic conductivity at saturation [m/s]
- h_{BC} : Air entry suction [m]
- Ω : Height between top of soil and the top of bordering the field edge [m]
- λ : Texture dependent retention shape parameter [-]

Which recharge mechanisms dominate at large scales in fractured rock?
What is the proportion of *localized and indirect* recharge to *total* recharge?

Indirect recharge in the drainage network plays an important role in recharging the aquifer, especially during dry years when soils are too dry to allow diffuse recharge