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

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Keywords: Recharge; Fractured crystalline rock; 1D unsat. flow modeling

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.

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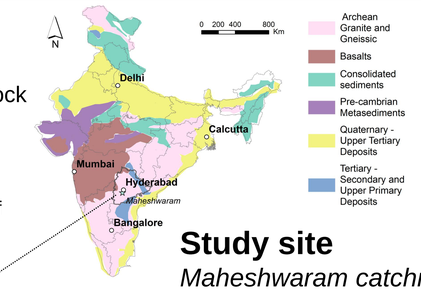
1. INTRODUCTION AND CONTEXT

Regional scale

Geology & Climate

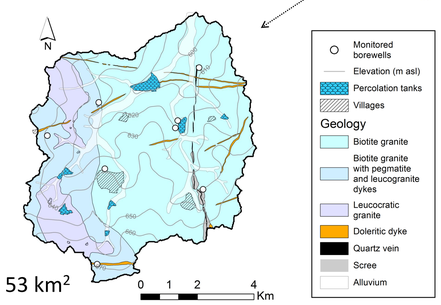
- Preponderance of igneous rock
  - Low yields
  - Intrinsic heterogeneity and complexity
  - Often only perennial source of freshwater
- Semi-arid climate



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

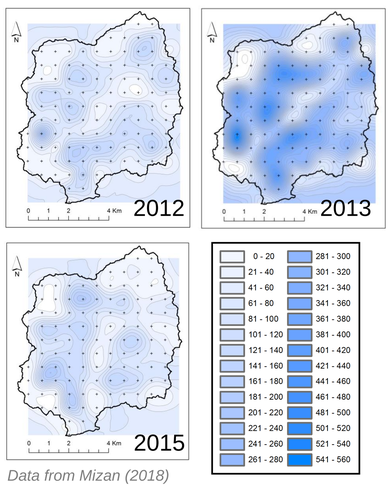


2. A COMPREHENSIVE MEASURE OF RECHARGE

Reference values

Recharge in space

→ Heterogeneous yet recurring recharge patterns



Data from Mizan (2018)

Water Table Fluctuation (WTF) method

$$R + RF + \cancel{Q_{on}} = E + PG + \cancel{Q_{off}} + S_y \Delta h$$

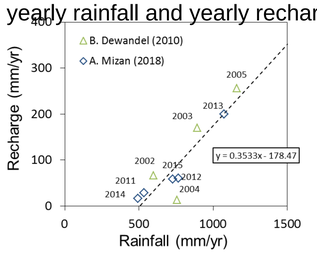
+ Easy and low cost application
+ Relatively accurate estimates

- 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

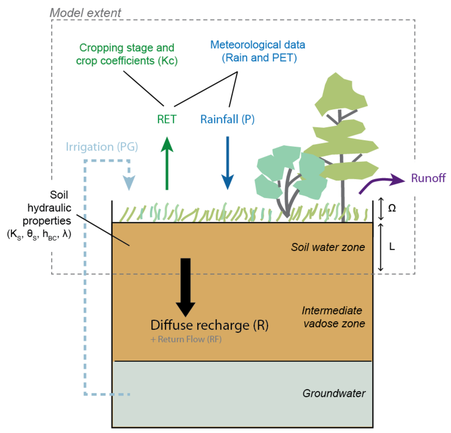


Which recharge mechanisms dominate at large scales in fractured rock? What is the proportion of *localized and indirect* recharge to *total* recharge?

3. METHODOLOGY

Model overview

Pseudo 2D hydraulic model



Unsaturated eqs.

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

Saturated eqs.

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

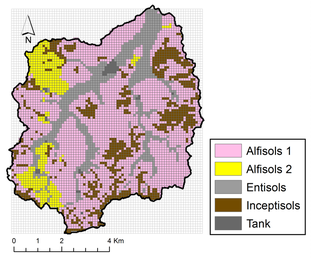
see Dewandel et al. (2006) & de Condappa (2005)

Model inputs

Gridded data from literature & database

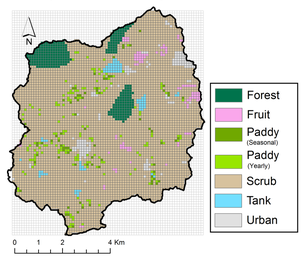
Soil Type

→ Soil hydraulic properties



Land Use & Land Cover

→ Inputs from irrigation and RET



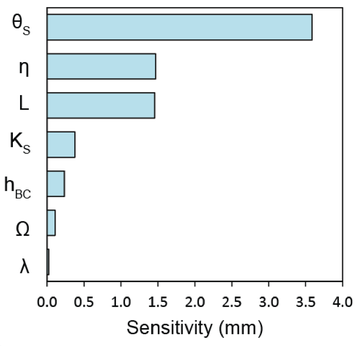
4. MODEL SENSITIVITY

Sensitivity Analysis

Determine effect of parameter uncertainty on recharge

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

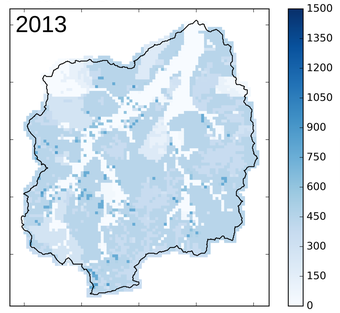
- $\boldsymbol{S_{i,t}}$: Normalized sensitivity of the ith input parameter at time *t*
- $\boldsymbol{O}$: Output function of the system
- $\boldsymbol{P_i}$: ith input parameter



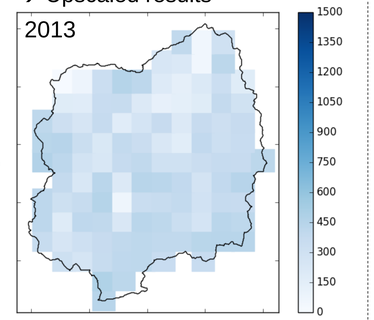
- ❖ $\boldsymbol{\theta_S}$: Volumetric moisture content at saturation [m^3/m^3]
- ❖ $\boldsymbol{\eta}$: Texture dependent retention shape parameter [-]
- ❖ $\boldsymbol{L}$: Soil thickness [m]
- ❖ $\boldsymbol{K_S}$: Hydraulic conductivity at saturation [m/s]
- ❖ $\boldsymbol{h_{BC}}$: Air entry suction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

5. RESULTS

→ Raw results



→ Upscaled results



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

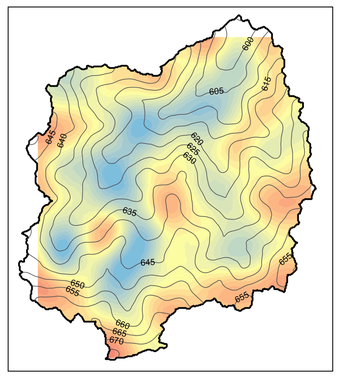
Outputs (mm)			Inputs (mm)	
Diff. rech.	*Runoff*	*RET*	*Rainf.*	*Irrig.*
92	107	725	845	121

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

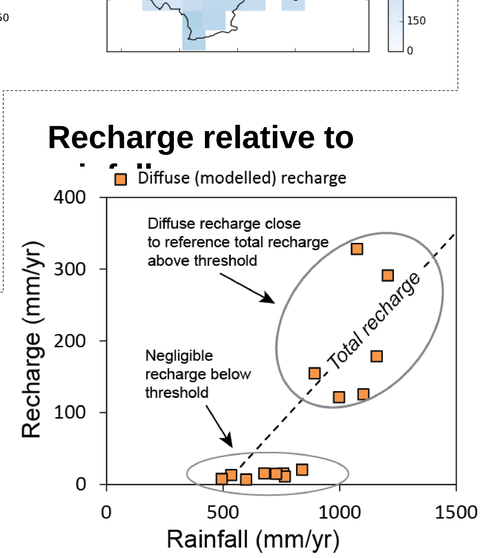
Recharge patterns

Focused recharge (mm/yr)

= Total rech. – Diffuse rech.



Recharge relative to



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

Topography [m asl]

Total rech. - Diffuse rech.

-90 - -80
-79 - -70
-69 - -60
-59 - -50
-49 - -40
-39 - -30
-29 - -20
-19 - -10
-9 - 0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90

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

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