Impact of MAR structure on groundwater quality in south-Indian crystalline aquifer: case study of Tumulur tank, Maheshwaram watershed

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I. INTRODUCTION

Managed aquifer recharge (MAR) structures like percolation tanks are particularly widespread in arid and semi-arid contexts as in southern India.
They are considered by the Indian national and regional governments as a major option for tackling declining groundwater levels due to overexploitation for irrigation purposes (Boisson et al., 2014). Their main purpose is to restore groundwater availability under strong climatic and anthropogenic pressure. Furthermore, MAR-induced dilution with fresh surface water is generally expected to improve groundwater quality with respect to both anthropogenic and geogenic contaminants (total mineralization, nitrates, chlorides, sulphates and fluoride contents). The impact of a percolation tank on groundwater quality was investigated in a context that is typical for hydro-climatic and geological settings in southern and eastern India: fractured crystalline basement aquifers overlain by a weathering zone under semi-arid climate. Water level data and chemical indicators (major ions) were monitored for both groundwater and surface water, over several successive monsoon events.

II. STUDY SITE AND METHODS

The Maheshwaram watershed is typical of the south Indian semi-arid context: heterogeneous weathered hard rock aquifer, irrigated agriculture dominated by paddy fields, heavy groundwater withdrawal and solute recycling issues. The potential annual evapotranspiration is about 1800 mm. The annual rainfall over the 1974-2013 period was 870 mm (minimum: 530 mm in 1985 and 2011, and maximum: 1450 mm in 2000). Precipitation occurs mainly during the highly variable monsoon period, usually from June to October. The bedrock of the catchment is mainly biotite granites and leucocratic granites with some quartz veins and dolerite dykes intruding these granites (Figure 1). The local weathering profile at the Tumulur area is typical of crystalline aquifers, usually defined from top to bottom by 1) a few tens of meters of thick saprolite layer (also called regolith), derived from bedrock decomposition and 2) Below the saprolite, the fractured layer. The latter constitutes the main transmissive zone of the aquifer, due to its subhorizontal and subvertical fissures network. Details on the tank functioning and efficiency can be found in Boisson et al. (2014).
Water levels and electrical conductivity (EC) in the tank and in the boreholes were recorded using data loggers recording at 15-minute intervals. In addition, GPS tracking was performed twice a month to assess the evolution of the water surface of the tank.
Water chemistry and stable isotopes content were determined based on samples collected in the 7 MHT boreholes, 3 additional farm wells and the Tumulur tank for major ions analyses during the 3 identified successive monsoon periods (period I, period II and period III) between June 2013 and November 2013.

Chemical data were analyzed using the Diagramme software. Simulations of surface water evaporation (batch reaction) were run using PhreeqC software.

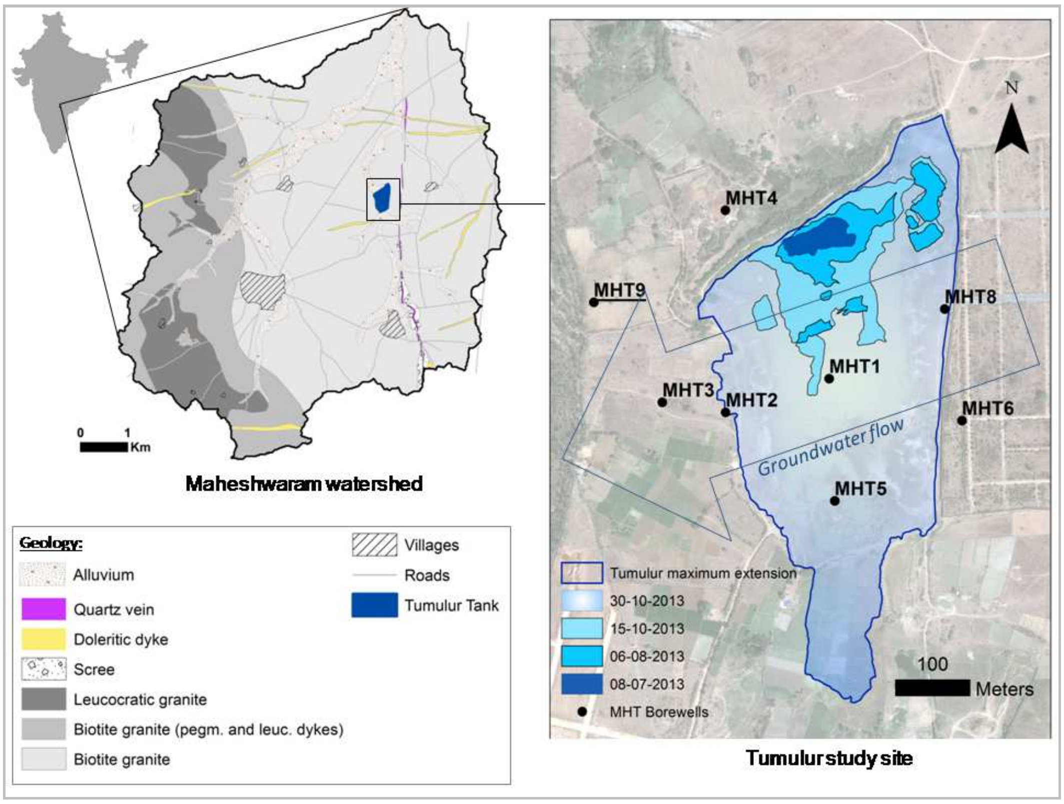


Figure 1: Left: Study site location, and geological main features. Right: Main boreholes (MHT) location and Tumulur tank extension area over the 2013 hydrologic year. Direction of the groundwater flow at the study site scale.

III. RESULTS AND DISCUSSION

Groundwater quality is highly variable, in both time and space at the study site scale. EC in MHT boreholes varied from less than 400 µS/cm to 3500 µS/cm. The dominant chemical facies of the groundwater is neutral to HCO_3-Na, but it can vary from Ca-Cl facies to very strong HCO_3-Na facies for a few boreholes (not shown).

In a few cases, the quality of the groundwater can be negatively impacted due to leaching of salts under the tank, particularly at the beginning of the monsoon, as seen on the EC time series (Figure 2). Dilution of groundwater is noticeable in several MHT boreholes (MHT2, MHT3, MHT4 and MHT9) during late stages of the monsoon, i.e. period III (Figure 2).

The increase of mineralization is associated with a degradation of the water quality. For example, the MHT9 borehole underwent an important EC increase along with a significant peak of nitrates (>100mg/L, also identified for MHT4) during the early stages of the monsoon, identified as period II (Figure 3).

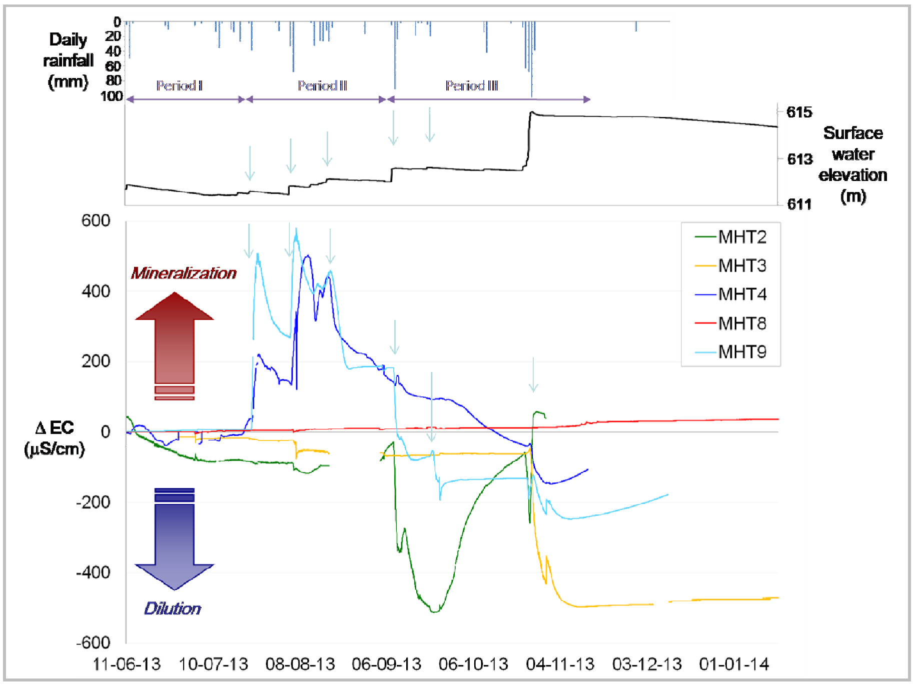


Figure 2: Up: Daily rainfall (mm) and surface water level (m) of the Tumulur tank for the 2013 monsoon. Successive periods of the monsoon (I, II and III) and main rain events are indicated. Down: Electrical Conductivity (EC) variations in the MHT boreholes over the monsoon season. Sudden changes in EC are marked with arrows. Corresponding arrows drawn on the Tumulur tank WL time series highlight that the EC variations are highly correlated with monsoon events.

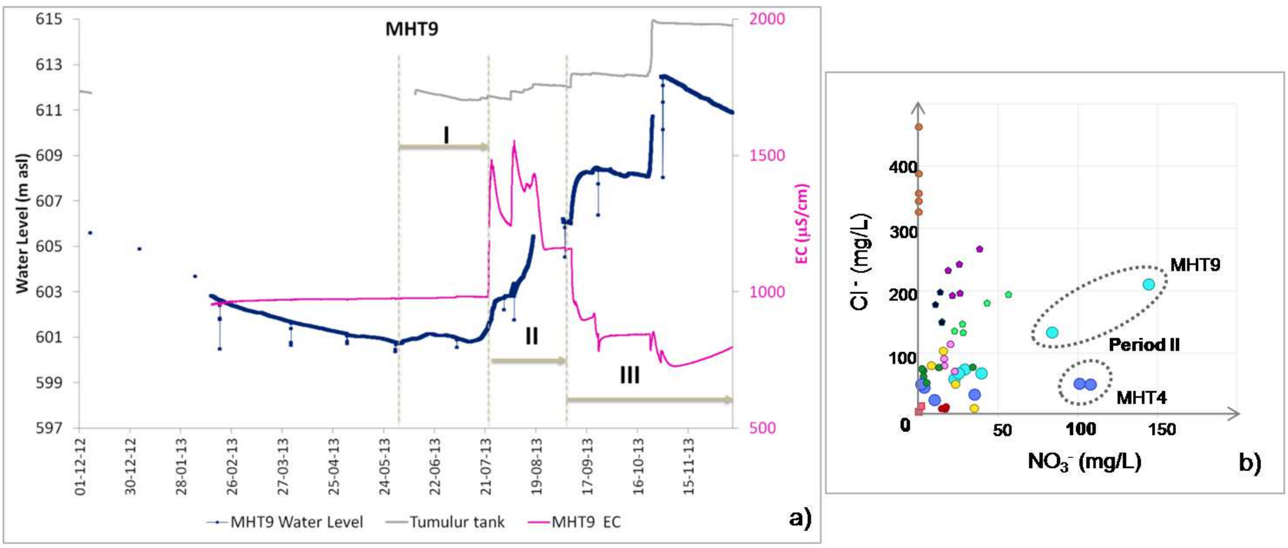


Figure 3: a) EC and piezometric time serie of MHT9 borehole and water level time series of the Tumulur tank. The 3 periods (I, II and III) are identified. b) Nitrates vs Chlorides contents (mg/L) for groundwater at the Tumulur study site. MHT4 and MHT9 boreholes show a strong content of Nitrates during the Period II (surrounded by dotted line).

Simple batch reaction simulation of evaporation processes of surface water and groundwater cannot explain the evolution of the chemical facies of the groundwater (Figure 4). The modification of chemical facies of MHT9 groundwater during the period II involves rock-water interactions, mixes processes and leaching of salts from the sub-surface, such as nitrates. As highlighted by the groundwater stable isotopes contents, the repartition of the dilution from the surface water in case of very high water levels (i.e. period III) is also heterogeneous (Figure 5).

The recharge processes inducing evolution of the groundwater quality are highly variable, in both time and space and tracing the groundwater pathways is a difficult task in these environments, as highlighted by the work of Alazard *et al*. (Under review) on this study site.

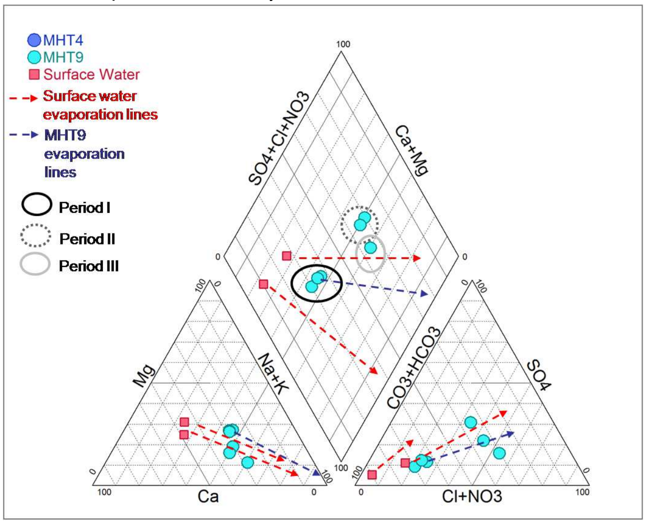


Figure 4: Piper diagram of the groundwater of MHT9 and surface water of the Tumulur tank and their evaporation lines computed with PhreeqC simulations (Batch reactions) highlighting that the evolution of the facies due to salt leaching cannot be simulated with simple batch reactions.

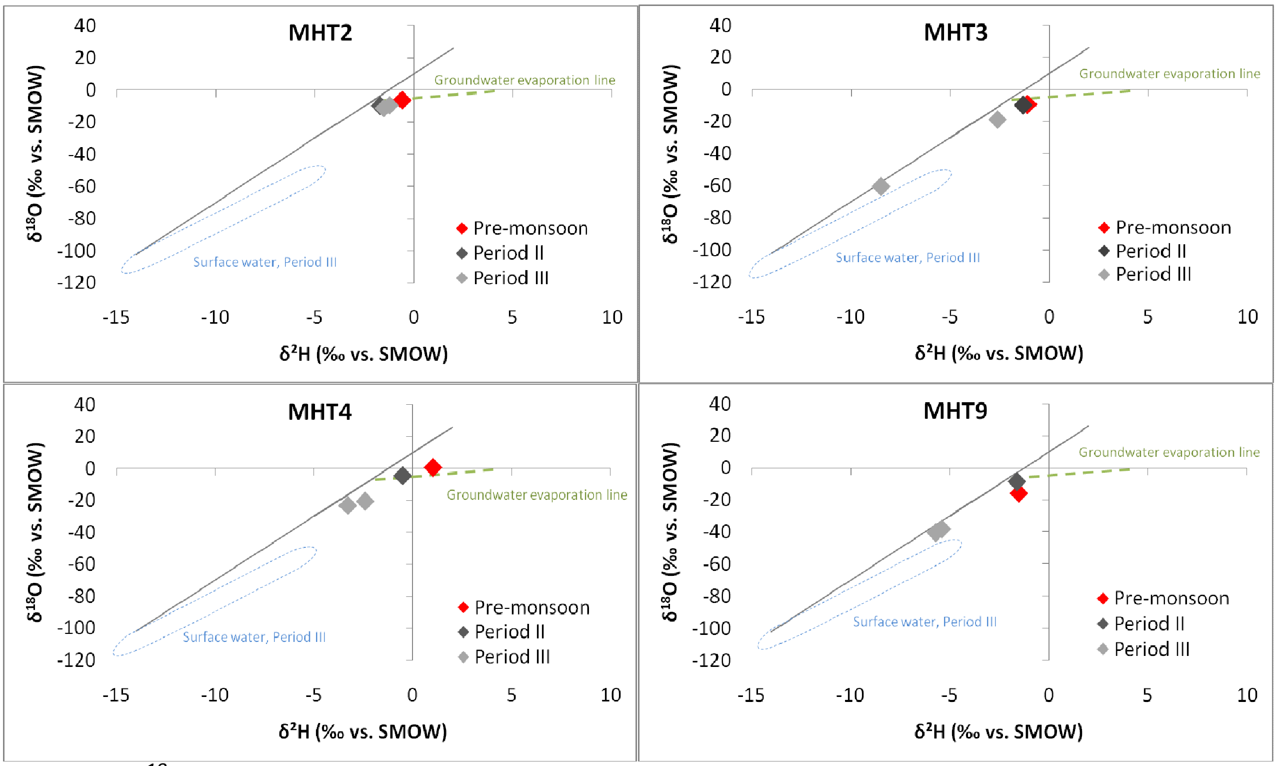
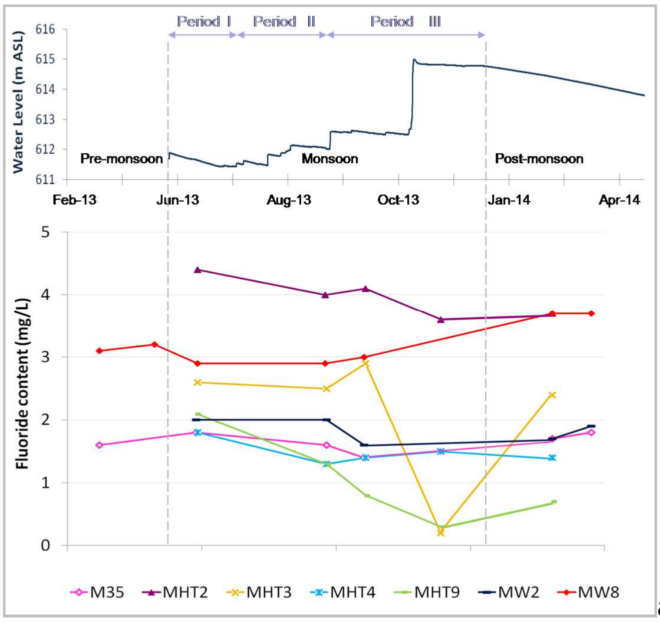
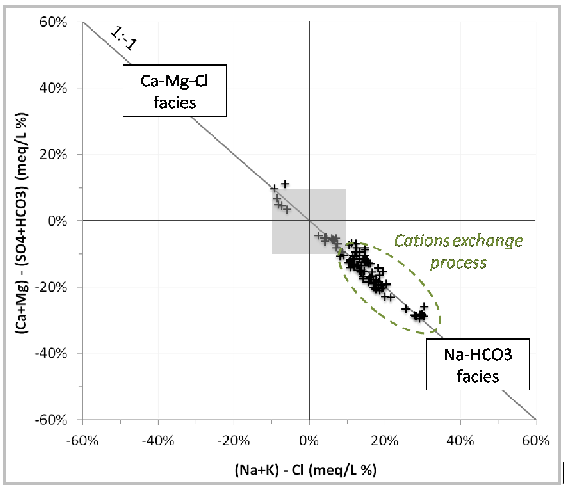


Figure 5: $\delta^{18}O$ vs δ^2H of MHT2, MHT3, MHT4 and MHT9 boreholes for the pre-monsoon period and 2 stages (Period I and II) of the 2013' monsoon. The groundwater evaporation line (light green dashed line) at the study site was defined in Alazard et al. (under review).The surface water isotopes contents during the period III of the monsoon are circled by the blue line. The boreholes signatures during the monsoon show varied impacts from the surface water.

Geogenic fluoride contents in groundwater, induced by water-rock interaction and enhanced by recycling of agricultural return flow under paddy fields, is found to be relatively stable over the year (Figure 6a). This finding points out that the underlying processes, mainly dissolution of F-bearing phases like fluorapatites combined with Ca/Na cation exchange and calcite precipitation, both limiting the possibility of F-removal via fluorite precipitation (Pettenati et al., 2013, 2014), are not impacted by the hydrological conditions (Figure 6b).



a)



b)

Figure 6: a) Evolution of the surface water level (m above sea level) and the Fluoride contents (mg/L) during the 2013 monsoon for 8 wells. b) Chemical facies of the groundwater for 2013 samples, dominated by cations exchange process, regardless of the hydrological conditions.

IV. CONCLUSION

This work highlights the complexity of the recharge processes in crystalline aquifers, enhanced by the variability of hydrological conditions. In a few cases, groundwater quality (EC, nitrates contents…) can be affected by salt leaching, mainly during relatively low water level periods, while the geogenic contaminants contents (Fluoride) are not positively impacted, even for very high water levels. This work provides insights into the possible risk for groundwater quality deterioration in cases of less abundant and short monsoons periods.

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