USE OF AQUIFER ANALOGS TO SUPPORT GUARANI AQUIFER GROUNDWATER MANAGEMENT

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Resumo

Padrões de fluxo das águas subterrâneas e de transporte de contaminantes na porção superior da Formação Pirambóia foram investigados, pela primeira vez no Sistema Aquífero Guarani (SAG), utilizando-se um aquífero análogo. Um experimento numérico foi realizado e os resultados obtidos sugerem que os sedimentos flúvio-eólicos dessa unidade estratigráfica representam uma parcela crítica das áreas de recarga do SAG, onde a caracterização de sítios contaminados e o planejamento de ações de remediação são potencialmente mais desafiadores. Esse estudo demonstra que aquíferos análogos são ferramentas capazes de melhorar o entendimento do SAG e de embasar políticas de gestão neste importante reservatório d'água.

Abstract

Groundwater flow and contaminant transport patterns at the upper Piramboia Formation were investigated, for the first time at the Guarani Aquifer System (SAG), using an aquifer analog. A numerical experiment was performed and the obtained results indicate that the fluvial-aeolian sediments of this stratigraphic unit represent a critical portion of the SAG recharge areas, where site characterization and planning of remediation actions are potentially more challenging. This study demonstrates that aquifer analogs are tools able to improve the SAG understanding and to support groundwater management policies in this important water reservoir.

Key words

Guarani Aquifer, Aquifer Analog, Modeling, Groundwater Management

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1 – Introduction

The Guarani Aquifer System (SAG) is one of the most important Brazilian groundwater reservoirs and, therefore, a strategic resource for future water demands [1]. The SAG is predominantly confined or semi-confined, with direct recharge primarily occurring only in 10 % of it, i.e., in its outcropping areas, which are considered to be of crucial importance for the SAG conservation, environmental protection and sustainable development [1]. According to [3], it can be inferred that approximately 40 % of the potentially critical areas for groundwater use in São Paulo State correspond to SAG outcropping zones (Figure 1). More specifically, 56 % of the Botucatu Formation and 26 % of the Pirambóia Formation outcropping regions are classified as high vulnerability areas.

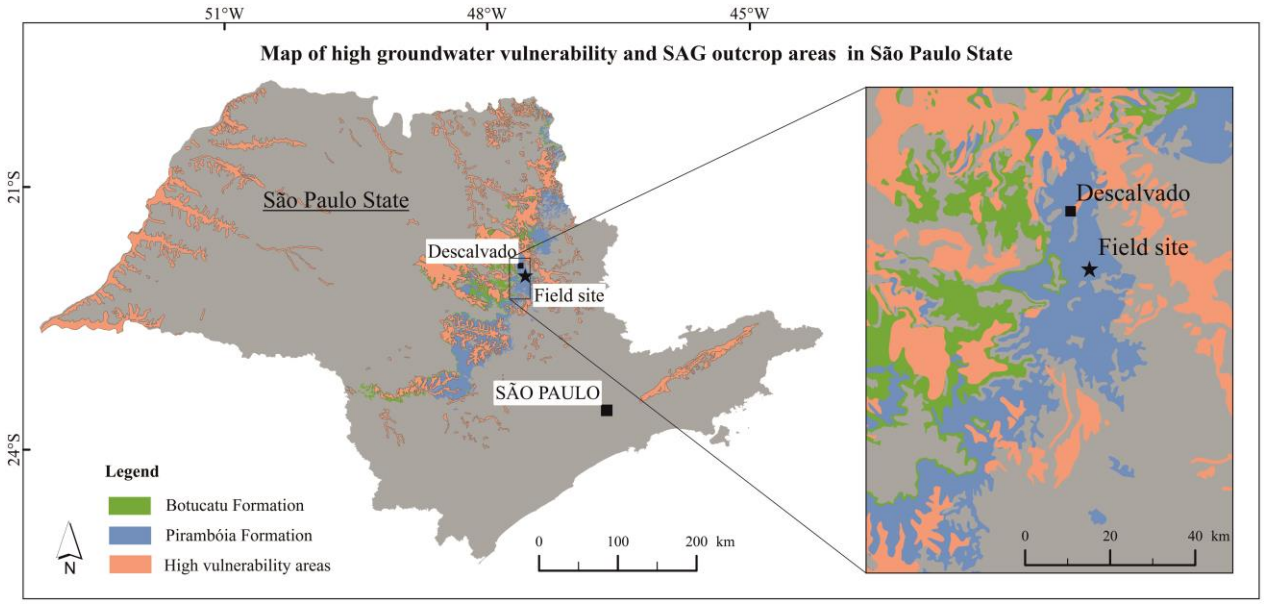

Figure 1. Areas potentially critical for groundwater use [3], SAG (Botucatu and Pirambóia formations) outcropping areas and aquifer analog location (field site) in São Paulo State.

In order to obtain deeper understanding on the groundwater flow and contaminant transport patterns at the recharge areas of SAG, a numerical experiment was carried out using a recently constructed aquifer analog of fluvial-aeolian sediments of the upper Pirambóia Formation [4]. The aquifer analog was constructed at a site close to the city of Descalvado [SP] (Figure 1) and represents the first aquifer analog built at SAG [4].

The generated three-dimensional and high-resolution aquifer analog provides significant insights into the heterogeneities and hydrogeological properties of the examined sedimentary unit. Therefore, it constitutes an ideal platform for (i) performing numerical experiments and for supporting the (ii) development of conceptual site models and (iii) groundwater management strategies at areas where the same type of sediments occurs.

2 – Analog Model Development

Sedimentary facies were meticulously mapped from three frontal outcrops, 28 m × 5.8 m, and two lateral outcrops, 7 m × 5.8 m in an open-pit sand mine. Field and laboratory hydrogeological investigations were conducted to derive hydrofacies types (zones of equal hydraulic conductivities) from the mapped lithofacies. Variations of hydraulic conductivity (K) and porosity (n) were then resolved on a 5 cm scale and finally presented in cross-sectional profiles [4] (Figure 2). A more detailed description of the aquifer analog construction is presented in [4].

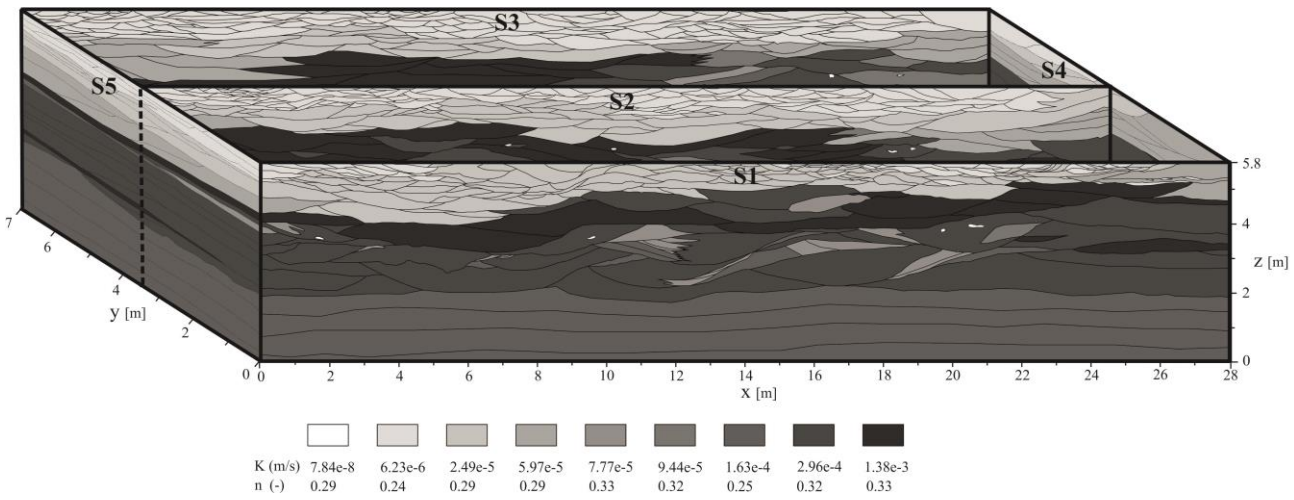

Figure 2. Three-dimensional aquifer analog of SAG fluvial-aeolian sediments (upper Pirambóia Formation) in the city of Descalvado (SP), modified from [4].

The constructed aquifer analog shows moderate hydraulic heterogeneity and a mean K value of 1.36×10^{-4} m/s, which is greater than the reported range of K values (from 5.78×10^{-6} m/s to 4.63×10^{-5} m/s) for the entire SAG in São Paulo State [5], as discussed in [4].

3 – Numerical Modeling

The aquifer analog profile S1 was used in a numerical experiment in which steady state groundwater flow conditions were simulated with MODFLOW 2005, assuming a hydraulic gradient of 1×10^{-4}. Subsequently, the model MT3DMS was applied to investigate the advective-dispersive transport of a solute released from a hypothetical constant source zone placed at the entire left border of the model, i.e. the model inflow boundary. A Matlab® script was then developed and applied to visualize the results. According to the 3,000 simulated days (Figure 3), the solute transport at the investigated SAG sediments is very heterogeneous, with preferential flow paths, i.e., flow focusing, occurring at thin layers with a K value of 1.38×10^{-3} m/s, which is 2 orders of magnitude higher than the SAG highest K reported value [5].

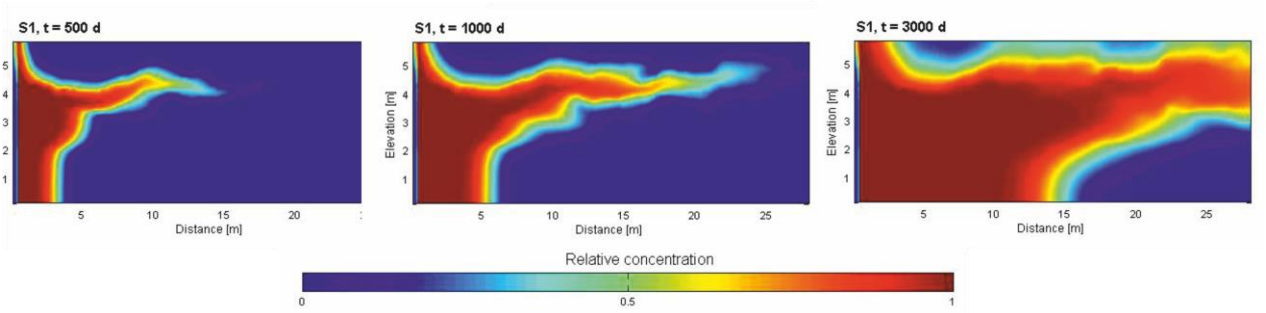

Figure 3. Simulated relative concentrations after 500, 1,000 and 3,000 days.

4 – Conclusions

Although in São Paulo State the outcropping area of Pirambóia Formation is circa 40 % larger than the Botucatu Formation outcropping area, most of the SAG recharge zones classified by [3] as high vulnerable correspond to Botucatu Formation outcrops. However, the aquifer analog study of [4] indicates that the upper Pirambóia Formation is one of the most permeable portions of the entire SAG and, consequently, might represent a critical parcel of its recharge areas. The model results (i) illustrate the potential contaminant migration patterns within the examined sediments and (ii) indicate that underestimations on contaminants first arrivals are likely to occur when average K values are used to define protection zones of groundwater production wells at this SAG portion. The model outcomes also suggest that site characterization and planning of remediation actions, e.g., in situ treatments, at this sedimentary unit are potentially more challenging than in other more homogeneous (e.g. Botucatu Formation) or less permeable (e.g. lower Pirambóia Formation) SAG compartments. We consider that further aquifer analog studies at SAG can considerably improve the overall understanding of the reservoir and support the refinement of groundwater management policies at each mappable SAG unit.

5 - References

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