Applying the Forchheimer equation to model an artificially recharged fractured aquifer: a case study of the Windhoek aquifer

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In the last decades artificial recharge has attracted the attention of many countries where groundwater has been depleted or as a means of enhancing aquifer recharge where natural recharge is being severely affected by climate change. The Windhoek aquifer is the case study, where artificial groundwater recharge is practiced annually, depending on the availability of surface water. The aim of this study is to assess whether managed aquifer recharge (MAR) is the permanent alternative to store sufficient water for supply to the City of Windhoek in times of drought. In this work, mathematical models depicting the flow of water within a fractured aquifer with permeable and impermeable rock matrices were considered to depict the flow of water within an artificially recharged aquifer. Using two different types of differential operators, two models were suggested- i) a model based on the classical differentiation which does not consider the heterogeneity of the geological formation; and ii) a model based on a nonlocal differential operator, which is able to include into mathematical formulation the effect of long-range dependency expressing the memory. For the classical case, the Laplace transform operator was used to derive the exact solution. For the nonlocal case, new numerical methods including Adams Bashforth and Atangana-Seda scheme were used to provide approximate solutions. For each numerical scheme stability and convergence analysis were presented with numerical simulation for different values of fractional order. Results show a normal flow within a homogeneous medium for classical numerical simulations; and a fast-flow and slow-flow within a heterogeneous medium for fractional derivatives. The complex and heterogeneous characteristics of the Windhoek aquifer prohibit the injected water from recharging the entire aquifer, because of complicated fracture interconnectivity and the faults which act as barriers to flow. The study proves that artificial aquifer recharge is limited and unsustainable for a long period to ensure water security for the city of Windhoek.