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Aquifer storage and recovery, and managed aquifer recharge of reclaimed water for management of coastal aquifers

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ABSTRACT

The hydrological and economic feasibility of aquifer storage and recovery (ASR) of excess desalinated water and managed aquifer recharge (MAR) using tertiary treated wastewater (TTWW) to manage stressed coastal aquifers in Oman has been studied numerically using the code, MODFLOW 2005 and the different transport packages MT3DMS, and MODPATH. The current ASR study aims to assess the feasibility of saving and recovering water for the purpose of supply to the city of MUSCAT during high demand periods by banking excess-desalted water during winter and recover it during the rest of the year. The second objective of the study is to explore the feasibility of MAR using TTWW to mitigate salinity in two costal aquifers in North of Oman exploited for different purposes: domestic water supply (Al-Khod aquifer), and for irrigation purposes (Jamma aquifer). ASR in the Al-Khod Aquifer was explored using Simulation Optimization multi-objective modeling using evolutionary algorithm NSGA-II (namely, the Non-dominated Sorting Genetic Algorithm-II), to generate the set of Pareto optimal solutions according to recharging scenarios. The results show that the potential net benefit of storage and recovery might reach as high as $17.80 million/year. The maximum profitable volume that can be recharged into the aquifer, given the limited number of wells and their locations, is estimated at 8.4 Mm^3/year, which is lower than the current excess estimated of 10 Mm^3/year. For MAR using TTWW, different managerial scenarios were simulated and analysis of the results reveals that the Jamma aquifer will further deteriorate in the next 20 years if it remains poorly managed. The groundwater level will decline further to exceed 3 m on average, and the iso-concentric salinity line of 1,500 mg/L will advance 2.7 km inland that will severely affect farming activities in the area. However, MAR using TTWW when integrated with the management of groundwater abstraction (e.g., smart water meter, higher irrigation efficiency to reduce the abstraction rate) becomes hydrologically feasible to augment the aquifer storage and controlling seawater intrusion, and hence sustains farming activities. The economic analyses of such situation recommend: (1) injecting TTWW in the vicinity of irrigation wells; (2) investing in smart water meters and online control of pumping from the wells to reduce the abstraction rate by 25%; and (3) a combination of both are feasible scenarios with positive net present values. Recharge in upstream areas is found not economically feasible because of high investment cost of the installation of pipes to transport the TTWW over a distance of 12.5 km. Because the financial resources for investments are limited, scenario (2) shows a Net Benefit Investment Ratio of 4.41 (i.e., investment of a $1 yields $4.41). Although option (3) shows the lowest Net Benefit Investment, it is very attractive from a social perspective because it entails an integrated demand and supply management of groundwater. Farmers are requested to reduce pumping, and the government will invest in injecting TTWW to improve groundwater quality in the vicinity of irrigation wells and to form a hydrological barrier to control seawater intrusion in the long run. The primary objective of MAR for the Al-Khod aquifer is to increase the urban water supply and to sustain the aquifer service with the lowest possible damages from seawater intrusion. A number of managerial scenarios were simulated and progressively developed to reduce seawater intrusion and outflow of the groundwater to the sea. An economic analysis was conducted to characterize

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the trade-off between the benefits of MAR and seawater inflow to the aquifer under increased abstraction for domestic supply. The results show that the abstracted volume for domestic supply can be doubled under MAR practices if irrigation wells are properly managed and public wells are better located. Even though injection of TTWW is more expensive (due to the injection cost), will result in higher benefits. The results indicate that managing the aquifer would produce a net benefit ranging from $8.22 million to $15.21 million compared with $1.57 million with the current practice. MAR using TTWW is feasible to develop water resources in arid regions, and the best scenario depends on the decision maker's preference when weighing the benefits of MAR and the level of damage to the aquifer. MAR, as a smart water governance technology, mitigates stresses on aquifer systems in arid zones, maximizes the benefit of using groundwater for both agricultural and domestic purposes while minimizing the adverse socio-hydrological and agricultural consequences of mismanagement of commingled groundwater-TTWW resources at all scales (national, catchment, metropolitan area, village, farm).

Keywords: Managed aquifer recharge; Aquifer storage and recovery; Salinity; Coastal aquifer; Oman