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Groundwater mixing pattern and origin of salinization in the Azraq Oasis, Jordan, revealed by noble gases

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Azraq Oasis, located in the eastern Jordanian desert, is an important freshwater resource of the country. Shallow groundwater reserves are heavily exploited since the 1980s and in consequence the groundwater table dropped by about 25 m and important wetlands dried out. Furthermore, some wells of the major well field show an increasing mineralization over the past 20 years. The fact that only a few wells show this behavior is surprising since the wells are situated quite close together and are mostly drilled to the same depth. A previous study using conventional tracers did not yield a satisfactory explanation [1].

Application of dissolved noble gases reveals the complex mixing pattern leading to the very localized salinization within the well field. It is found that the wells affected by salinization 1) contain distinctly more radiogenic ^{4}He than the other wells, indicating higher groundwater age, and 2) exhibit a significantly enhanced ^{3}He/^{4}He ratio, implying an influence of deep mantle fluids. Since the hydrogeologic system in the Azraq Oasis comprises of three aquifer systems, separated by poorly permeable layers and traversed by several deep fault systems, mantle influence is expected to be found in the deeper aquifers. The data, therefore, indicate upward leakage into the shallow aquifer.

However, the saline middle aquifer is virtually free of mantle helium. To our knowledge, this is the first time a groundwater system is described where mantle helium is found in an aquifer lying on top of one which is free of mantle impact. This behavior can be explained by an upstream from an even deeper (and saline) source through a nearby conductive fault, while the groundwater flow direction in the middle aquifer is towards the fault and reversed in the shallow aquifer, towards the well field.

This scheme explains how the mantle fluids (and also most probably the increased salinity) infiltrates into the shallow aquifer, but not why only few wells are affected. The shallow aquifer consists of chalky limestone and a far more permeable basalt shield on top. Because the boreholes of the well field have no casing, water is potentially abstracted from all depths. Initially, however, by far most water was abstracted from the basalt aquifer due to the different permeabilities. As the groundwater table dropped, the basalt layer fell progressively dry and subsequently more water from the deeper part of the shallow aquifer was incorporated into the well's discharge – which according to the presented scheme is affected by salt and mantle fluids. The local depletion depends strongly on the individual cone of depression around a borehole and, therefore, can explain the local occurrence of the salinization phenomenon. The admixing of deep groundwater is further supported by warmer discharge temperatures and other parameters.

[1] Al-Momani et al. (2006), IAEA TecDoc 1507, 177-211