

New evidence for the origins of salinity in the coastal aquifer of Agadir, Morocco using ion and isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{34}\text{S}$)

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ABSTRACT

The coastal plain of Agadir is enclosed between the High Atlas Mountains, in the north, and the Souss River which represents the principal collector of the Souss river basin, in the south. In the west it opens to the Atlantic Ocean over a length of 8 km and has an average width of no more than 10 km. The area comprises an unconfined multilayer aquifer made by sandy and shelly limestone, alluvial fans, estuarine deposits and sandy formations. The base consists of blue marls with a thickness of several hundred of meters. Groundwater flows towards the ocean with hydraulic gradient of 2-3 ‰ and transmissivity of $3-7 \times 10^{-2} \text{ m}^2/\text{s}$. Since the 1960s, increased economic activity and population growth have led to intensive exploitation of groundwater and deterioration in water quality in this area. The total dissolved solids (TDS) in many wells have increased on average from 1 to 10 g/L over 50 years. Under present conditions, three water types are observed: (1) Na-Cl⁻ water that characterises the area around Agadir; (2) Na-Cl⁻ type but with relatively high sulphate concentration near Ait Melloul city, 10 km from the ocean; and (3) Ca-Mg-HCO₃⁻ type which prevails in the upland portions of the study area and in southern coastal sand hills in which waters are fresh, indicating recharge occurring in these areas.

A recent multi-tracer ($^{87}\text{Sr}/^{86}\text{Sr}$, $\delta^{34}\text{S}$, Br⁻/Cl⁻, B/Cl⁻) investigation has improved constraints on salinity sources. Water type 1 can be generated by mixing of local Ca-Mg-HCO₃⁻ water at equilibrium with calcite (type 3), mixed with <10% seawater or a saline water with seawater-like composition. Along this mixing trend, Br⁻/Cl⁻ approaches the seawater value of 1.5×10^{-3} at high salinity. Low-salinity waters exhibit slightly depleted values suggesting that local groundwater also derives salts from evaporite sources. In addition, water type 1 is affected by Ca/Na ion exchange. $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are consistent with cation exchange, as the observed $^{87}\text{Sr}/^{86}\text{Sr}$ cannot be obtained from mixing of seawater with Tertiary limestone in marine terraces or with Jurassic gypsum in the adjacent Atlas foothills. Boron concentrations and B/Cl⁻ are also consistent with expected base-exchange reactions in which removal of Na coincides with the adsorption of B to clays. Based on $\delta^{34}\text{S} < 0 \text{ ‰}_{\text{CDT}}$, water type 2 contains sulphate derived from marine sulphide oxidation, possibly mixed with evaporitic sulphate, but not with modern seawater. Overall, deterioration of water quality may occur not only from increased mixing of seawater, but also from other natural salinity sources, urban wastewater, and agricultural waste.

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