

## Multiple origin of water salinization in a coastal aquifer, Bay of Bengal

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**Abstract** The multi-layered aquifer of the Kaluvelly basin has been selected because an increase in salinity, together with a drastic decline in groundwater level, have been recorded for several years in the main exploited aquifer of the area, the Vanur aquifer. Currently it displays a reversed flow from the sea and swamp. inland. Salt may originate from numerous sources: (a) seawater intrusion through the upper aquifer bordering the coast; (b) lateral seawater migration due to increase of the pumping rate; (c) brackish water from the swamp during seasonal monsoon; (d) upward leakage of highly mineralized water from the underlying aquifer caused by modification of the head gradient due to the pumping increase; (e) vertical downward movement of salty irrigation water; and (f) enhancement of leaching of sediment beds due to drainage increase. Initial results indicate that salt could originate from upward leakage of highly mineralized waters.

**Key words** coastal aquifer; geochemistry; hydrodynamic; salinization; India

## INTRODUCTION

For several years, the multi-layered aquifer of the Kaluvelly basin has shown an increase in salinity associated with a drastic lowering of the water level (Auroville Water Service, 1998). We focus our attention on the Vanur sandstone aquifer. It is the main aquifer in the area exploited for agricultural purposes. Firstly we will try to characterize the different water bodies involved and their seasonal evolution, and to address some issues about the origin of salinization. Second, a water balance analysis and modelling of the water circulation is undertaken. Results will be used to aid water management and planning in the area. Only the first step will be discussed here. The setting of the Kaluvelly coastal basin is characteristic of the Bengal coastal zone. Our approach is intended as a pilot study. One hydrological year (four collections, 2000–2001) has been monitored during dry, wet and intermediate seasons, on the two main, and some minor aquifers, Fig. 1.

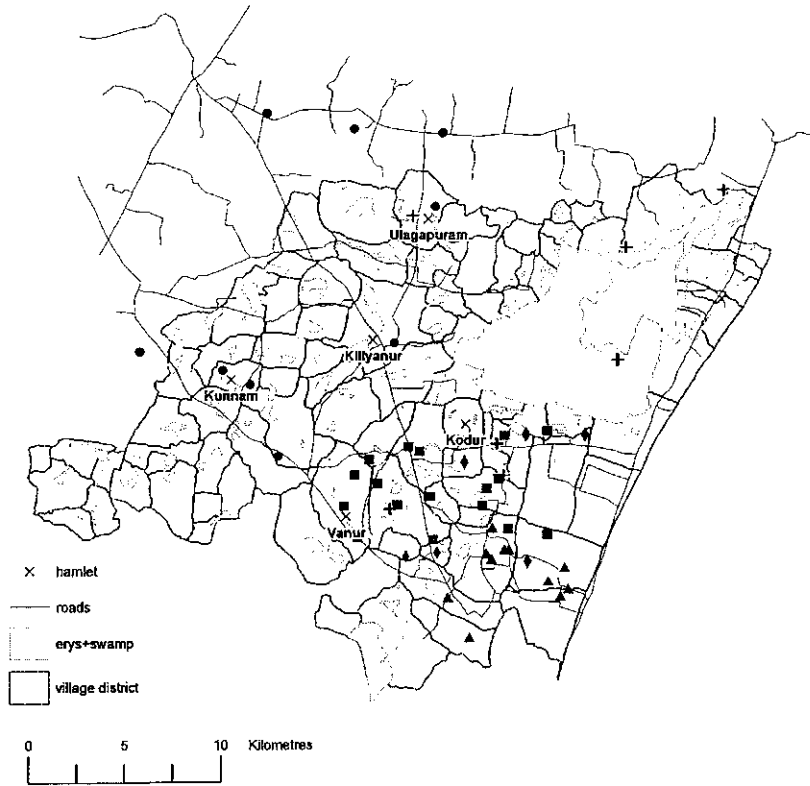


Fig. 1 Sample location. For symbol legend, see Fig. 2.

## GEOLOGICAL AND HYDROLOGICAL SETTINGS

The Kaluvelly basin is located on the Bengal coast between Chennai (Madras) and Pondicherry, Tamil Nadu, India. The 730-km<sup>2</sup> drainage basin is comprised of a crystalline bedrock (charnockite) hinterland overlaid by sedimentary layers near the coast (Table 1). The sedimentary cover constitutes a multi-layered aquifer: two main layers, the Vanur sandstone and Cuddalore sandstone; three minor layers, two sandstone layers and one calcareous layer, separated by aquitards. Disconnected and ephemeral streams and water supply tanks (erys) replenished by natural recharge constitute the surface drainage pattern. The brackish Kaluvelly swamp occurs at the outlet of the drainage basin before it enters the sea. This area is characterized by a tropical climate with long dry spells, and a mean annual precipitation of 1200 mm (Pondichery station), which occurs mostly in the monsoon season (October to December), which allows recharge to the aquifer, and from June to August.

The over-exploitation of the Vanur aquifer has modified the natural groundwater flow, which nowadays is reversed and flows inland from the sea and swamp. The pumping is discontinuous and irregular, is not evenly distributed geographically, and leads to unpredictable flow. Most wells in the area are not cased, which results in some mixing between the confined Vanur aquifer and the overlying aquifers.

**Table 1** Stratigraphic sequence of geological formations in Kaluvelly watershed.

Stratigraphy	Geological formation	Lithology
Pleistocene	Alluvium–Laterite	Sands, clays, loam, gravel, laterite
Mio–Pliocene	Cuddalore	Sandstone and coarse conglomerate
Palaeocene	Manaveli	Limestone
Palaeocene	Kadaperikuppam	Calcareous sandstone
Upper Cretaceous	Turuvai	Limestone, sometimes conglomeratic
Upper Cretaceous	Ottai	Clays with thin calcareous beds
Upper Cretaceous	Vanur	Quartz sandstone slightly argillous
Lower Cretaceous	Ramanathapuram	Argillous sandstone with lignite beds
Archaean	East. Ghat Complex	Charnockites and gneiss

Salt may originate from multiple sources: (a) seawater intrusion through the upper aquifer bordering the coast; (b) lateral seawater migration due to an increase in pumping rate; (c) brackish water from the swamp during the seasonal monsoon; (d) upward leakage of highly mineralized water from the underlying aquifer caused by modification of the head gradient due to the pumping; (e) vertical movement of salty irrigation water (downward transfer); and (f) enhanced leaching of sediment beds due to drainage increase. Initial results indicate that salt could originate from the upward leakage of highly mineralized waters.

## RESULTS

### General characteristics of the system

The three main exploited aquifers and their chemical characteristics are briefly summarized in Table 2. Waters from the Cuddalore and the Vanur are clearly different; charnockite waters display various signatures as shown in Fig. 2. The data highlight localized points of interest such as: (a) high salinity waters in sand lenses in the Ottai clays (one of the aquifers located between Cuddalore and Vanur), and (b) local interaction of the swamp and adjacent aquifers.

**Table 2** General characteristics of waters from the Cuddalore, Vanur and charnockite aquifers.

Aquifer	Facies	Saturation index (average)	Characteristics
Cuddalore	CaHCO <sub>3</sub> 100 to 500 $\mu\text{S cm}^{-1}$	calcite: -2.82 chalcedony: saturated	rapid circulation; little water-rock interaction
Vanur	CaHCO <sub>3</sub> to CaCl 600 to 1800 $\mu\text{S cm}^{-1}$	calcite: -0.27 chalcedony: saturated fluorite: -0.66	marked evolution from unconfined to confined zone; water-rock interaction
Charnockite	CaHCO <sub>3</sub> to NaCl 500 to 2200 $\mu\text{S cm}^{-1}$	calcite: -0.16 chalcedony: saturated fluorite: -0.95	discontinuous aquifer; two distinct facies

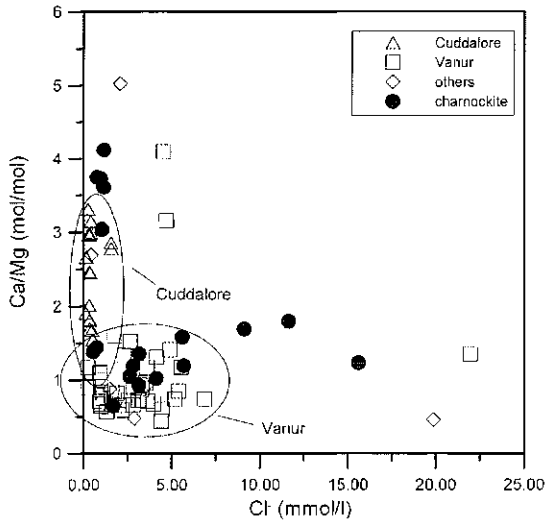


Fig. 2 Molar concentrations of Ca/Mg versus chloride in the Cuddalore, Vanur and charnockite aquifers for January 1999, October 2000 and January 2001.

### The Sr isotope record

Sr isotope ratio measured in the sampled waters is nearly constant from October 2000 to January 2001. It can be considered as a conservative tracer of water–rock interactions and used as a fingerprint of water origin and/or flow paths. Sr isotope data are reported through a mixing diagram, Fig. 3, which exhibits four end-members corresponding to: (a) seawater; (b) Vanur aquifer highest ratios; (c) charnockite aquifer lowest ratios; and (d) Cuddalore aquifer intermediate values characterized by low Sr contents (high  $1/Sr$  values). According to sample 6, recharge by the crys could be possible in the Cuddalore (phreatic aquifer). Sr isotope ratio allows us to clearly distinguish charnockite waters from Cuddalore and Vanur waters. The Sr isotope ratio evolution between samples from the Vanur unconfined area and the confined area could be ascribed to water–rock interaction signature as the Vanur sandstone originates from charnockite erosion. Local fertilizer analyses suggest the Vanur aquifer highest ratio may be due to fertilizer input through infiltration of irrigation water.

### Evaporation

$\delta^{18}O$  et  $\delta D$  data water samples do not show any evaporation rate sufficient to explain the recorded salinity.

### Piezometric data

Piezometric data from the Vanur aquifer show a deep hydraulic depression on the southeast area indicating a flow path direction coming from the sea and the swamp

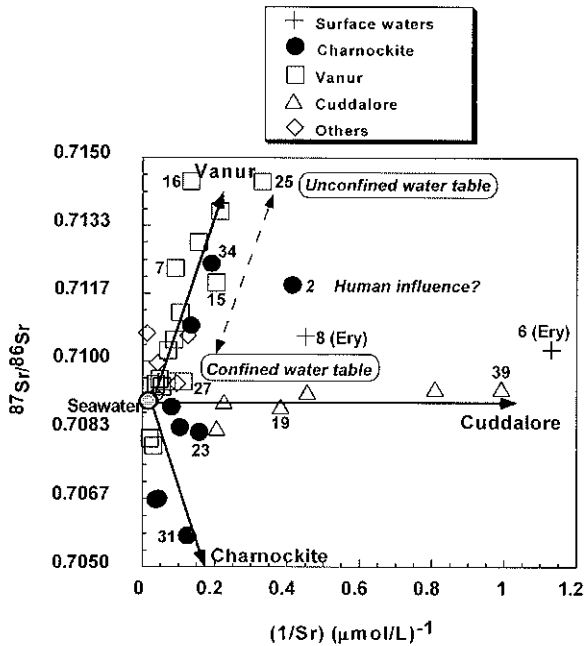


Fig. 3 Evolution of  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio versus  $1/\text{Sr}$  for October 2000.

inland. Nevertheless this piezometric map should be used with caution as the number of points is limited and the values may reflect an hydrodynamic impact of all the surrounding pumping (more than 1000 borewells).

This depression location and the occurrence of sulphate-rich waters (often the more mineralized) are well correlated. This could be evidence of an upward leakage of highly mineralized waters not sourced in the charnockite, but more likely from a smaller aquifer interbedded between the charnockite and the Vanur aquifer units, namely the Ramanathapuram sandstone aquifer (iron and sulphate-rich waters in reductive conditions).

## CONCLUSION

From this preliminary study, it has not been possible to conclude whether salinization is primarily due to seawater intrusion or infiltration of salty irrigation water caused by evaporation. Results show an upward input from saline waters in reductive conditions of the Ramanathapuram sandstone aquifer underlying the Vanur aquifer.

**Acknowledgements** The authors thank Naturalia & Biologia, Auroville Water Service, and INSU-ACI 'Inde' for encouraging and supporting this work.

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