# Effects of Past Climate Change on Hydrochemistry and Hydraulics in two Large Aquifers in S and SE Asia

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S and SE Asia are densely populated and this refers in particular to the fertile delta plains of the major rivers. Several megacities and their supply areas are situated in or close to the deltas. Hanoi lies in the Red River delta, Ho Chi Minh City in the fringe of the Mekong delta, Bangkok on the Chao Phrya delta, Rangoon in the Irrawaddy delta and Dhaka and Calcutta in the Ganga-Brahmaputra delta. The water requirement is large, both for water supply and for irrigation. The extensive aquifers underlying the delta are attractive both for water supply and irrigation. The groundwater is often of a good quality and the investments for utilising it is very reasonable. This has led to overdraft resulting in deterioration of quality and settling of the ground (Ramnarong, 1991).

The delta areas are built up by complex sediments ranging in age from the Tertiary until recent. Depending on variations in the past climate they consist of alternating layers of finer and coarser sediments reaching thicknesses of several hundred to even several thousand metres.

## The coastal Kerala aquifers

### *Hydrogeology*

The coastal plain in Kerala in SW India is underlain by sediments ranging in thickness up to about 400 m and width up to 50 km (Fig. 1). The oldest sediments are of Tertiary age and the coastal strip is covered by recent sand-dunes (Nair & Rao, 1980). The sediments are relatively much more extensive than the size of the river catchments indicate. This is due to the tilting over of the Indian peninsula towards the East as a consequence of tectonic movements brought about by the collision of the peninsula with the Eurasian continent and the uplift of the Himalayas. This means that the Peistocene and Holocene sediments are thin on the West coast of the peninsula while they are rather much thicker on the East coast.

Four aquifers are distinguishable, from below the Vaikom, the Quilon, the Warkali aquifers and the recent sand-dunes. The three lower aquifers are confined towards the coastline. Especially the Warkali aquifer is subject to a considerable withdrawal, lowering the head below the sea level in the area south of Alleppey. Worries are raised about the possibility of seawater intrusion (Gottshalk et al., 1988).

### *Hydrochemistry*

There is a clear zonation in the water quality from south towards north along the coast in the Warkali aquifer (Fig. 1). In the south $Ca\text{-}HCO_3$-waters dominate, turning into a $Na\text{-}HCO_3$-type of water south of Alleppey before the dominance of brackish Na-Cl-waters comes north of the Vembanad lake (Subramanian, 1980). The pattern is similar in the Vaikom aquifer, however shifted a bit southwards.

This looks like a fresh water flushing of a formerly saline aquifer with a natural softening through ion-exchange resulting in the Na-$HCO_3$-waters (Fig. 2) (Mercado, 1985; Appelo, 1994). The flushing should then proceed in a SE to NW direction. This interpretation is, however, clearly contradicted by the low heads existing in parts of the area (Gottshalk et al., 1988).

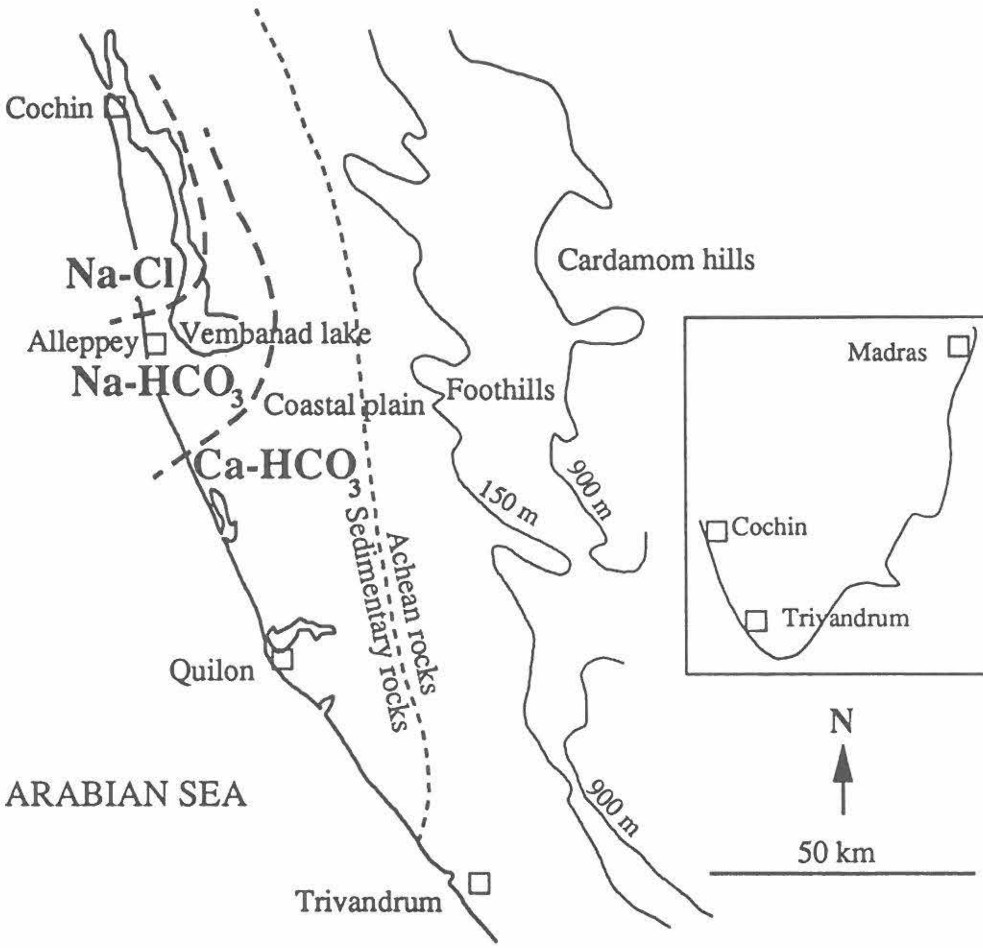


Fig. 1. Zonation of groundwater chemistry in the Warkali aquifer in the coastal Kerala plain, SW India.

The past seawater levels may give the key for interpreting the hydrochemical pattern as well as it may explain the apparent inconsistencies between the water chemistry and the present low heads. The Flandrian transgression was rather small on the Indian West coast (Pirazzoli, 1991). The seawater level during the Pleistocene were about 120 m below the present sea surface, pushing the shoreline about 60-70 km offshore from the present one (Pirazzoli, 1991). This would during a few thousand years have given good opportunities for recharge and flushing of the aquifers (Fig. 3). The reason why the flushing has proceeded from the south may be due to the rather thin cover in the southeast by laterites giving less resistance to recharge than the more impermeable and clayey cover northwards.

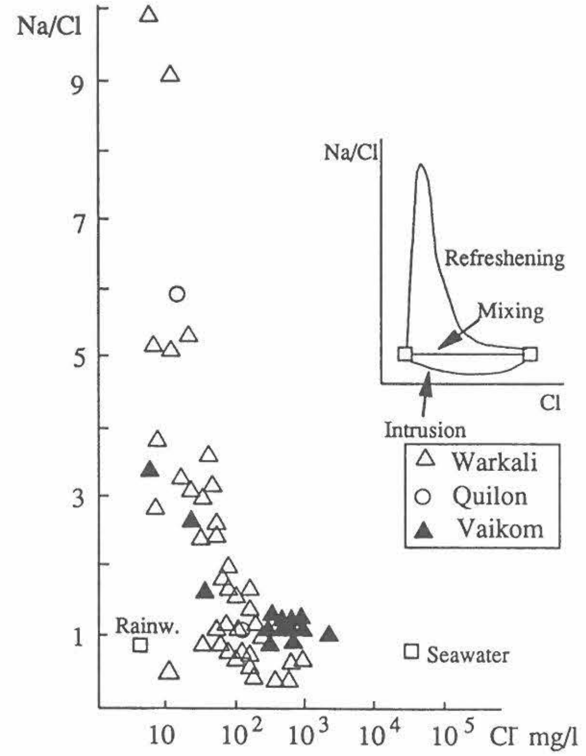


Fig. 2. Na/Cl ratios versus chlorinity for the Kerala coastal aquifers indicating both fresh water flushing and intrusion (graph after the design of Mercado, 1985).

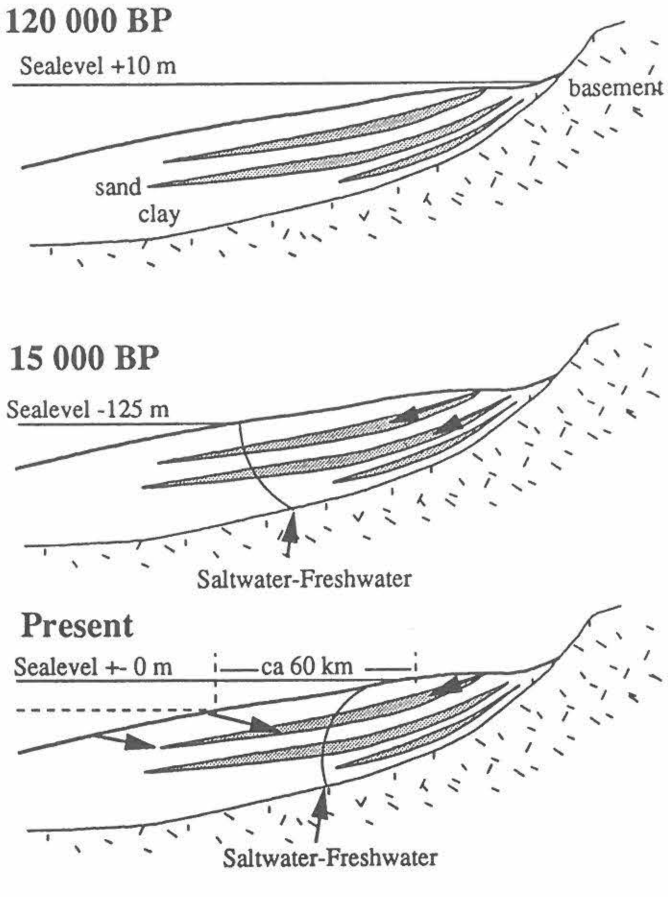


Fig. 3. Hypothetical groundwater flow pattern in the Kerala aquifers as influenced by the sea level changes.

## The Mekong delta

*Hydrogeology*

The on shore sediments in the Mekong delta dates from Oligocene to recent (United Nations, 1986). The Pleistocene sediments are thick, amounting to about 200 m in the mid-delta. The Holocene sediments are also thick, a fact brought about by the increasing population in the upland during the last few thousand years, resulting in the gradual disappearing of protecting forest cover and increased erosion (Nguyen Kim Cuong, 1989). Thus the delta has approximately doubled in size during the last 4000 years. This has also meant that the outer delta is slightly more elevated above the sea level than the inner delta which is the area which is generally flooded during events of high tide.

*Hydrochemistry*

The water qualities in the aquifers in the Mekong delta are inversed in the sense that the most saline groundwater with more than 3 g/L are found in the upper aquifers in the inner delta while the fresh waters of generally $Na\text{-}HCO_3$-type are found in the lower aquifers (Tran Hong Phu, 1990) (Fig. 4). The salinity in the upper aquifers is ascribed the Flandrian sea transgression about 6 000 years ago (Nguyen Kim Cuong, 1989). Due to the low elevation in the inner delta the salinisation has mainly hit the upper aquifers in the inner delta, seen to the left in Fig. 4. The fresh groundwater in the lower aquifers is of $^{14}C$-ages more than 10 000 years and this may be a similar phenomenon as in the Kerala aquifers, being flushing during the Pleistocene period with a seawater level of about 120 m below the present one. It is inferred from offshore drilling for hydrocarbons that freshwater may be present 20-50 km offshore in these aquifers (Nguyen Kim Cuong, 1986). However, today these freshwater aquifers are considered

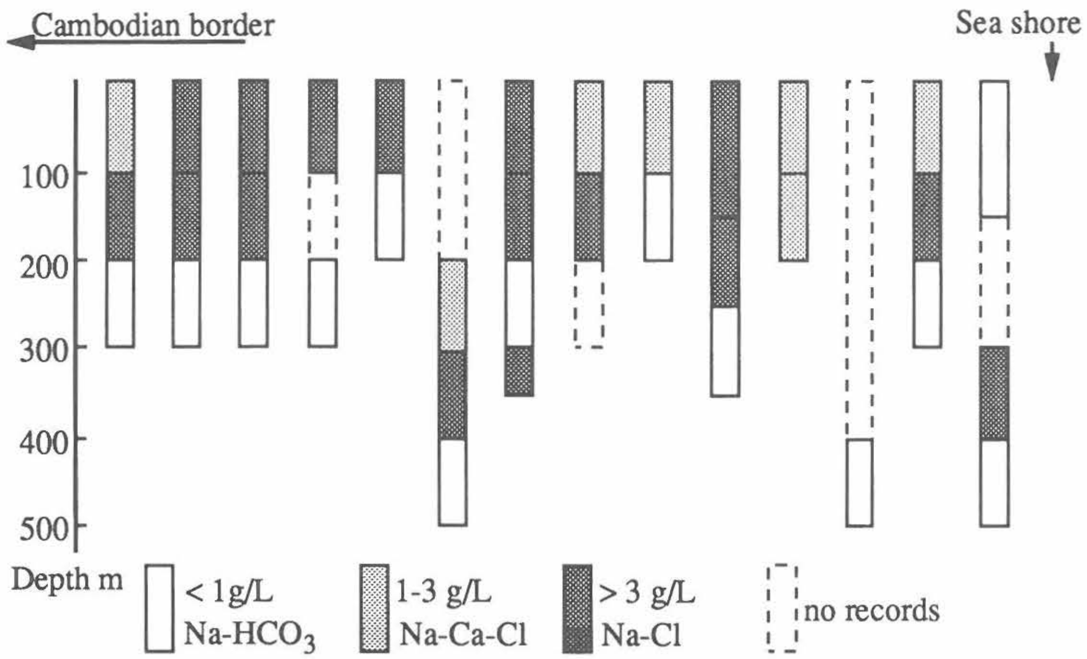


Fig. 4. Sections of water quality from wells in the Mekong delta from close to the Cambodian border downstream to the sea shore. Modified after Tran Hong Phu (1990). The low salinity waters are of the $Na\text{-}HCO_3$-type, the medium saline ones are of a mixed Na-Ca-Cl-type while the most saline are of the Na-Cl-type.

to be quite stagnant which warrants the conservative attitude adopted for their use by the Vietnamese legislation, not allowing them to be used for irrigation, only for domestic water supply.

## Conclusions

The two examples given here reflects the complexity of the hydrogeology in the delta areas. They have a four-dimensional character, three in space and one in time. It is essential to consider this in order to be able to exploit the groundwater in a sustainable way. For the Mekong delta a very conservative legislation has been adopted, allowing the use of groundwater only for domestic water supply, not for irrigation. A similar approach may be warranted in other areas as well. A network for hydrogeologists and hydrochemists working in these areas would be useful to transfer experience from one area to another, shedding light on similarities as well as on differences between sites. Another urgent task is to share the knowledge with decision makers, water users and legislators.

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