Groundwater quality in the Valigamam region of the Jaffna Peninsula, Sri Lanka

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Abstract: The Valigamam region is underlain by a Miocene limestone formation and a highly porous soil cover. The region is totally dependent on groundwater to meet its agricultural, industrial and domestic needs, since other sources of water are seasonal. Recharge from rainfall is limited by high run-off and evapotranspirational losses. The region experiences water supply problems due to high concentrations of chloride, total hardness and nitrate in groundwater. The spatial distribution of chloride varies from year to year, with maximum concentrations experienced during or after the wet season. The major factor explaining high chloride concentrations is the excessive extraction of groundwater that results in saline intrusion from the sea or lagoonal areas. In a large proportion of wells sampled for nitrate, levels exceed the WHO standard due to intensive agricultural practices involving very high inputs of artificial and natural fertilizers and the improper construction of latrine soakaway pits. To improve groundwater quality in the Jaffna Peninsula will require controls on the location of new wells, a revision of existing and future pumping rates and a change in agricultural practices. It is imperative that future work in the region should focus on combining groundwater management and sustainable agricultural practice.

A great deal of emphasis has been given to the study of hydrogeological systems in the dry zone areas of Sri Lanka, as the consumption of groundwater for domestic and agricultural purposes has increased dramatically over the last few decades (Christensen & Dharmagunawardhane 1986). The quantity and quality of groundwater in the dry zones are affected by natural processes that vary according to the geological, hydrogeological and climatic settings in each region, but human activities contribute substantially to the problems of groundwater resources and water quality in these areas.

The Jaffna Peninsula, which is part of the dry zone area in Sri Lanka, is underlain mainly by a Miocene limestone that is considered to be a good aquifer for groundwater storage and discharge. However, the region experiences groundwater problems as the resource is limited and its quality has deteriorated over the years (Arumugam 1969; Nandakumar 1983). Groundwater is the only source of water for the whole peninsula and there are currently no major water supply schemes. The seasonal rainfall is of short duration, and is the only source of recharge. High evapotranspirational loss during the dry season and high run-off loss during the wet season play a major role in determining the limited storage of groundwater in the peninsula.

The Valigamam region, which covers about 50% of the peninsula and which is relatively accessible, was chosen for the present study. This area was selected because severe groundwater quality problems had been identified in previous studies (Arumugam 1969; Nandakumar 1983). In comparison with the other areas of the peninsula, the Valigamam region is moderately highly populated. Intensive agricultural practices occur on thin soils directly overlying the shallow aquifer, from which water is used for both domestic and agricultural purposes. Agricultural practices are increasingly

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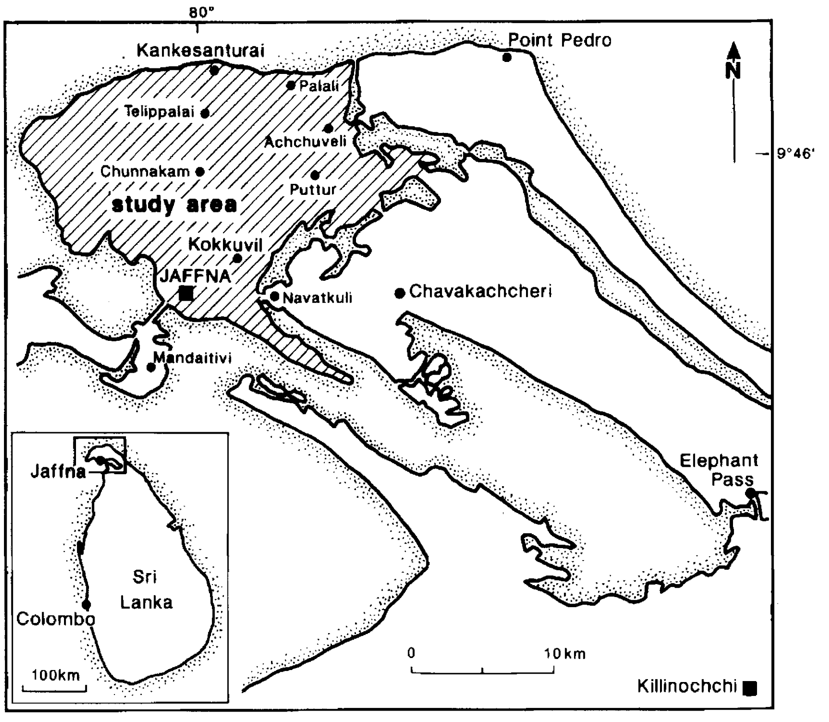

Fig. 1. Location of the Jaffna Peninsula and study area.

dependent on chemical fertilizers and pesticides for greater food production to meet the demands of local markets, and this trend has continued during the past two decades during a period of political instability.

The deteriorating quality of groundwater in the Jaffna Peninsula has justified continued water quality monitoring and investigation. A major water quality problem, identified in the 1950s and highlighted in the 1960s, is seawater intrusion into the groundwater system (Balendran *et al.* 1968). Later concern centred on the high nitrate problems related to high inputs of artificial and natural fertilizers and congested or improperly planned soakaway pit systems. It has been suggested that 80% of the wells in the peninsula are affected by high nitrate concentrations (Gunasekaram 1983).

Since 1979, a number of government and private organizations have initiated a systematic water quality monitoring programme; however, this came to an abrupt end in 1984 due to the unsettled political situation, with the result that the consequences of saline intrusion and the intensification of agriculture on the underlying groundwater are not well understood. It is unfortunate that the vast amount of data collected by government and private authorities from 1972 to 1984 was incomplete and was recorded in a disorderly manner. One of the better systematic surveys was organized by the Water Resources Board (WRB) during the period 1972–1984 in order to determine the levels of chloride and total hardness, including monthly readings, from 543 selected sample wells. In addition, the WRB collected a few borehole and shallow tubewell drilling records. However, much of the unpublished water quality data and water level maps are unavailable at present.

The primary objective of the present study was to carry out a systematic survey of groundwater quality in the Valigamam region by measurement of various parameters (chloride, total hardness, nitrate, sulphate, fluoride, electrical conductivity and pH) and compare variations in their distribution to different geological and geographical environments. The survey reported here emphasizes the distribution and interpretation of chloride in groundwater. The study was carried out between August 1997 and February 1998, to determine seasonal variations during the driest period that prevails before the rainy season (August) and the following wet

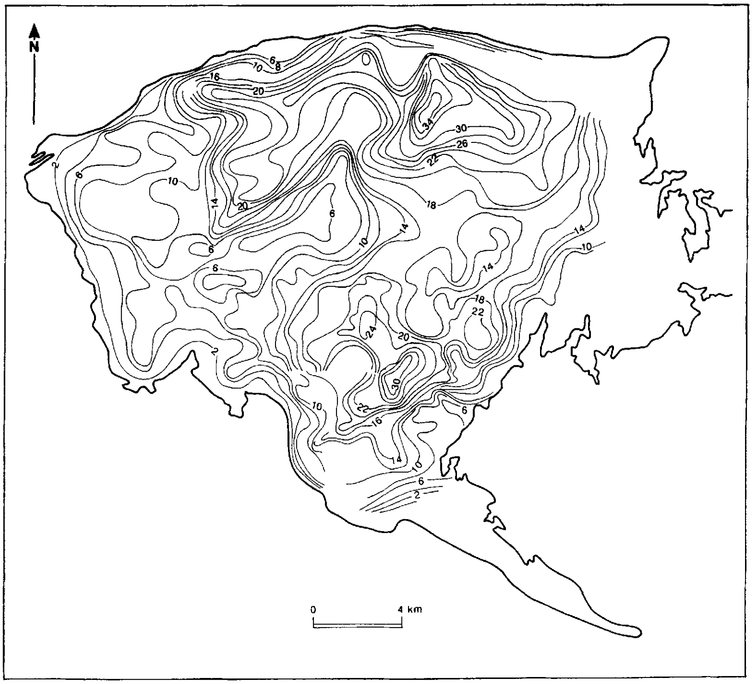

Fig. 2. Topographic map of the study area (contour lines in feet; 1 foot = 0.305 m).

period caused by heavy depressional rains (December). A secondary objective was to compile and reinterpret the groundwater quality data obtained in the previous detailed investigations of the Jaffna Peninsula so as to examine changes during the intervening 15-year period and to suggest remedial actions that should be taken to manage the groundwater resource.

Physiographic setting

Geography

The Jaffna Peninsula is located in the northern part of Sri Lanka. The Valigamam region covers approximately 325 km^2 and is bordered by straits and lagoons. No point within this area is more than 8 km from the sea (Fig. 1). The topography of the area is low and flat. The elevation varies from >35 to <1 m with an average elevation of less than 12 m above mean sea level (MSL) (Fig. 2). The area is devoid of any perennial rivers with the exception of a small intermittent rain-fed stream called the 'Valukai aru', which also drains a few very minor canals in the Jaffna area.

The area experiences a tropical arid climate. The average maximum daily temperature is 30°C and the minimum is 25°C. Winds blowing during the north-east monsoon (December to February) and the south-west monsoon (May to September), at average velocities of 40 km h^{-1}, intensify evaporative losses that amount to about 2000 mm per year (Arumugam 1970; Yogarajah 1991). The mean annual rainfall is approximately 1255 mm and falls mainly during the inter-monsoonal seasons due to depressions moving in from the Bay of Bengal and the Arabian Sea. Surface drainage is minimal under ordinary or light rainfall conditions, but since most precipitation falls during a short period – sometimes 50% within 24 h (Nandakumar 1983), surface run-off is usually very marked. This surface run-off is concentrated in shallow ephemeral channels, the small canals and the Valukai aru mentioned above, and may lead to flooding and overland sheet flow (Balendran *et al.* 1968).

The Valigamam region may be divided into nine major land-use categories that include built-up land and associated non-agricultural land (1.9%), homestead (45.6%), paddy (19.1%), coconut (2.1%), scrub (2.9%), marsh-

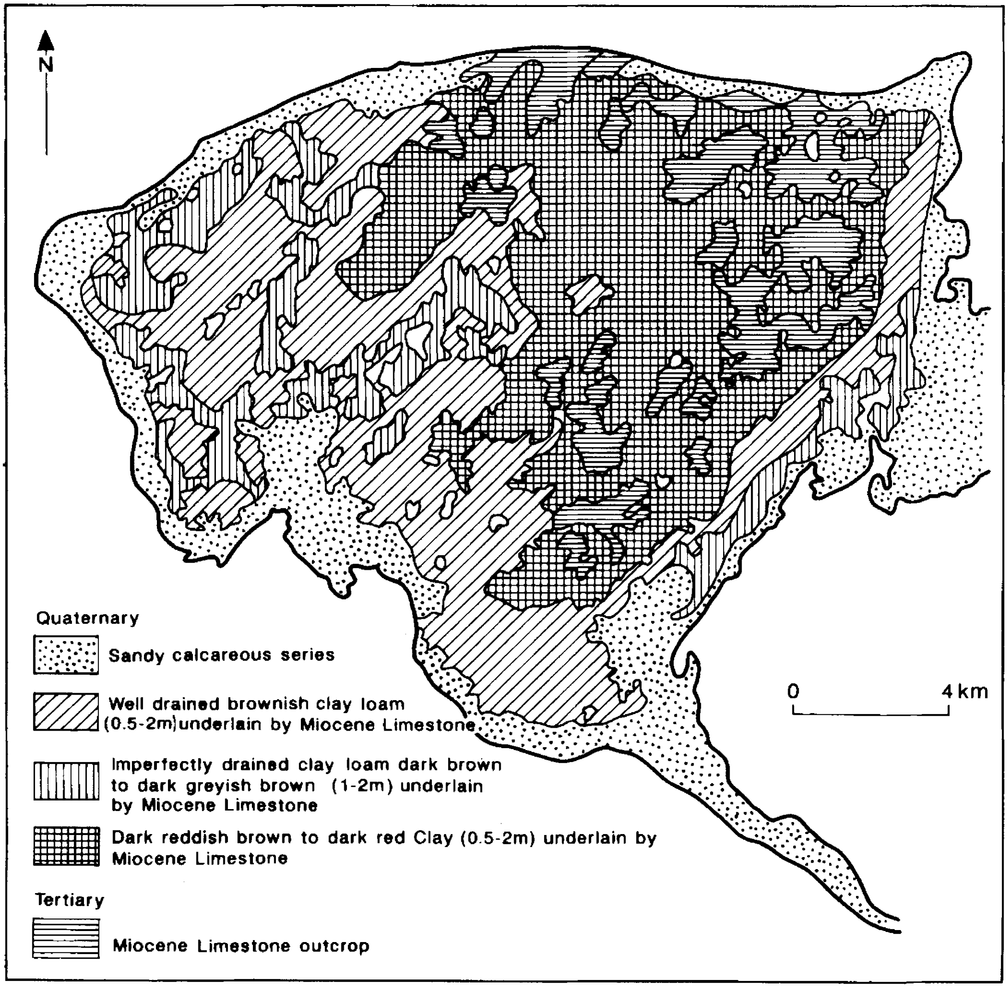

Fig. 3. Generalized soil and geology map of the Valigamam region. The inset map shows identified lineaments based on aerial photographic interpretation.

land (8.1%), sparsely used cropland (8.0%), barren lands (11.1%) and water bodies (1.2%). However, two categories, namely homestead (including gardens), and paddy, cover the major part of the study area. An important feature of the built-up land is the high density of population and housing, particularly in the coastal areas (3000 inhabitants km ^{2}) according to data from the 1981 population census.

Geology

A generalized soil and geology map is shown in Figure 3. The northern and the north-western coastal belt of Sri Lanka (stretching from Puttalam to the Jaffna Peninsula) represents the major sedimentary formation of the island. This formation consists mainly of Miocene limestone (Cooray 1984). In general, this Miocene formation unconformably overlies high-grade pre-Cambrian metamorphic rocks (the Wanni complex, formerly the West Vijayan complex) but in places is underlain by sedimentary layers of Upper Jurassic (Gondwana) age. In offshore drilling programmes, Cantwell *et al.* (1978) recognized sedimentary deposits from Lower Cretaceous to Pliocene age, separated by a number of unconformities (Cooray 1984).

The Miocene limestone of the Jaffna Peninsula is poorly bedded and generally flat, except in

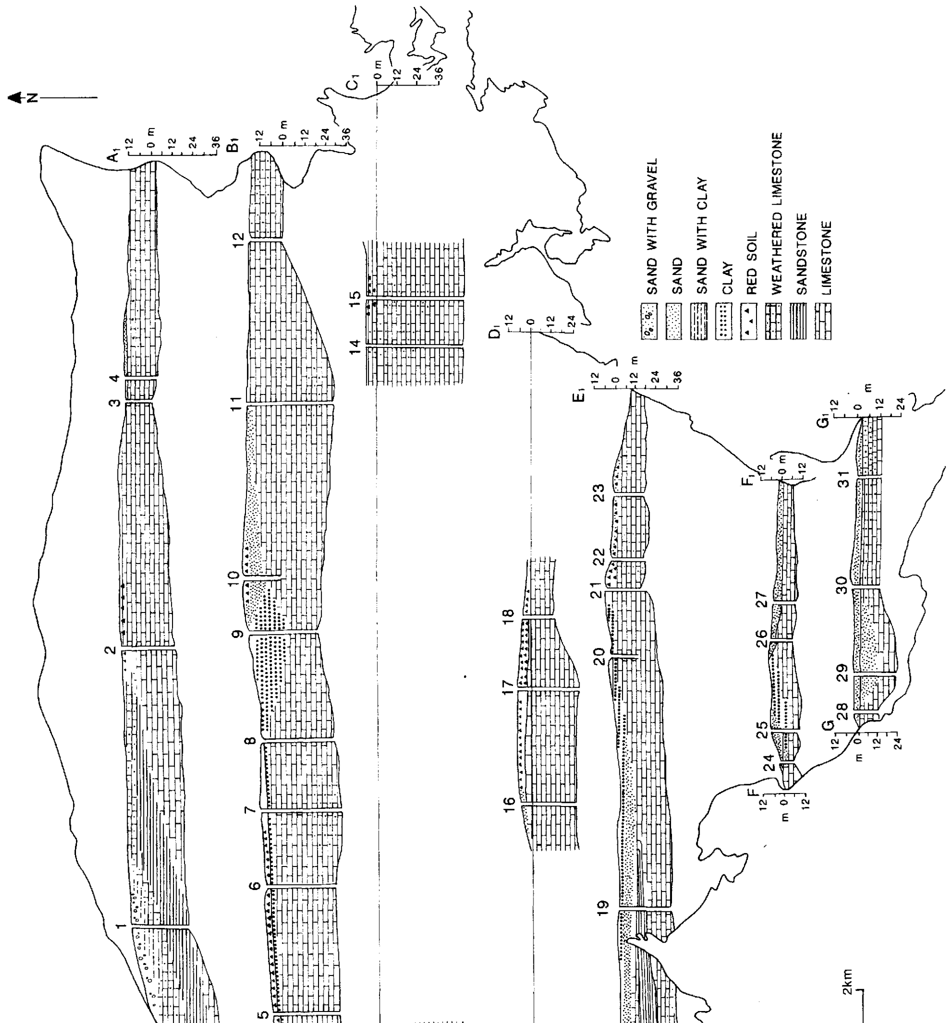

Fig. 4. Generalized cross-sections of the limestone formation in the Valigamam region.

some areas where it shows a slight dip to the west. In places the limestone beds are extremely well jointed and have a marked rectangular pattern of closely spaced joints running in north-west to south-east and north-east to south-west directions (Cooray 1984; Rajeswaran *et al.* 1993) Three lineaments, running in a north-east to south-west direction have been identified in the study area using aerial photographs and borehole information. These are in the Valukai aru basin, Upparu lagoon and Palali (Rajeswaran *et al.* 1993).

Lithologically the limestone is cream coloured varying from white grey to light brown, hard, compact, highly karstic, indistinctly bedded and partly crystalline. It also consists of sandy (siliceous) friable layers with cavities and clastic fossiliferous limestones. The limestone beds are intercalated with coral limestone beds and sandy limestone beds in the northern and southern parts of the study area. A sandstone bed is intercalated with limestone beds at a depth of about 5 m in the north-western part of the study area and this bed extends almost to the surface. The limestone is generally very fine grained but is slightly coarser and more porous where it contains fossils. This fossiliferous limestone contains many interconnected cavities that are mostly filled with calcareous clays. Generally, where the limestone is weathered it produces a yellow calcareous clay.

The vertical thickness of the Miocene limestone exceeds 35 m. In the north-east the limestone scarcely crops out, but there are a number of karstic features including surface depressions (e.g. at Manipay Idikundu), tidal wells (Puthur Nilavarai), cliffs and springs (Keeramalai). The limestone is generally overlain by highly porous thin (maximum 2 m) soil cover (Figs 3 and 4). Coral reefs are deposited around the northern coast and Quaternary red earth (Laterite), gravel and alluvium occur in the mainland (Cooray 1984). The red earth occurs as a thin layer (0–3 m) on the surface of the Jaffna limestone and in cavities, is poorly sorted and contains rounded river pebbles of different rock types. The associated reddish brown soils are deposited along the gentle undulating surface and calcic red yellow latasols occur at lower elevations (Gunesekaram 1983). Low humic clayey soils and alluvium are deposited mainly in the coasts and some parts of the mainland (Yogarajah 1991). The western, southern and eastern coastal regions of the study area are covered by a sandy calcareous soil series while red and grey earths occur inland (see Fig. 3). Beach sand is found as a narrow layer along the northern coast. Red and brown soils overlie a clay formation in the western coastal parts and the central part of the region. This clay formation extends to a depth of 16 m at Telippalai and gradually thins out towards the western coast where it is not mixed with the calcareous sand formation present.

Figure 4 shows generalized cross-sections constructed using the available borehole and tubewell logs. The borehole data reveal that the limestone is highly weathered in the central and the coastal areas at the surface and to shallow depths. In some locations, such as Kalundai, Telippalai and Vasavilan (boreholes 19, 9 and 11, respectively), the weathered limestone layers are intercalated or interbedded with hard limestone beds at different depths and thickness. At Maruthanamadam (boreholes 17 and 18), the weathered limestone beds are interbedded with calcareous sand and clay. Such sand and clay interbedding with the limestone occurs at shallow depths in most areas. The central, inland part of the region has a thick overburden consisting of highly weathered and permeable limestone, while the rest of the area lacks such conditions due to greater variability in the lithology of the interbedded limestone beds and the possibly greater uplift in the central area leading to enhanced weathering.

Hydrogeology

According to investigations carried out in 1997 (176 data points), the maximum water level in the study area in August (at the height of the dry season, i.e. groundwater level minimum) was 4.0 m above msl while in December (following the inter-monsoonal rains) it was about 5.0 m (msl). The groundwater level patterns for the period 1979 to 1997 show differences in water level elevations, especially during the dry season (August). The most significant feature (see Fig. 5) is shown for the year 1997, when the areas experiencing negative groundwater levels (below msl) were relatively large (26% of the study area). Furthermore, the areas with negative water level elevation had migrated inland in 1997 and are separated by areas with positive water levels. In 1997, a large part of the Jaffna Peninsula had negative water level elevations in both the wet and dry seasons. Excessive extraction of groundwater from wells, particularly from agricultural wells using highly efficient electrical pumps for prolonged periods, is the main cause of the reduction in groundwater elevations.

The pattern of groundwater movement in the study area between 1979 and 1997 has also changed in response to increased agricultural abstraction. In general, the direction of ground-

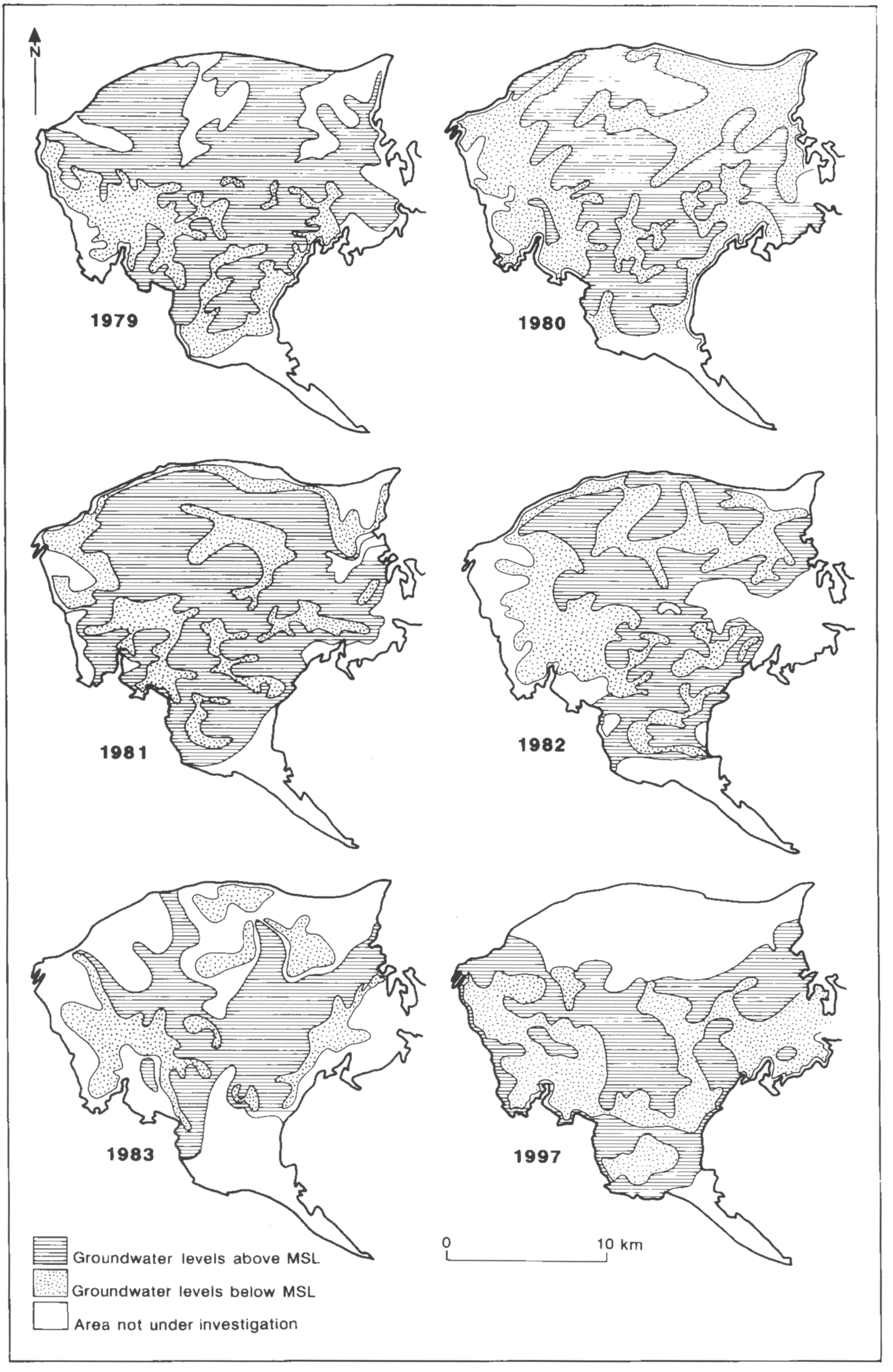

Fig. 5. Spatial distribution pattern of groundwater level elevation (1979–1997 August). Areas of groundwater levels under and above mean sea level (msl) are shown.

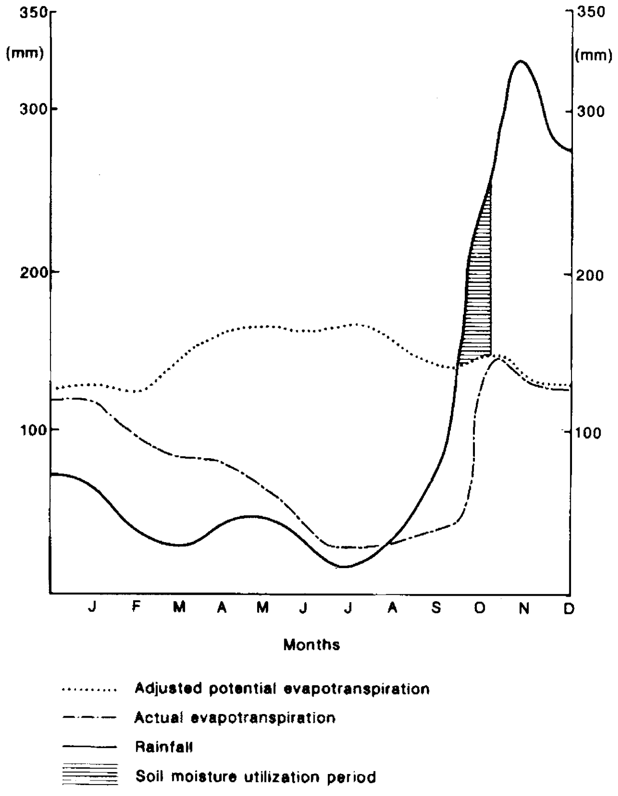

Fig. 6. Trends of annual surplus and deficit of water (rainfall) in the Jaffna Peninsula.

water movement is towards the southern, south-western and eastern coasts, where the negative water level elevations occupy relatively large areas (Fig. 5). It is important to note that the pattern of groundwater movement changes from year to year due to changes in the pumping regime.

Figure 6 shows a simplified water balance based on average monthly temperature and rainfall values for the Jaffna Peninsula over the past 50 years. The graph shows higher rates of average adjusted potential evapotranspiration (1764 mm a^{-1}) than actual evapotranspiration (1034 mm a^{-1}). Thus, an average deficit of 730 mm is typically maintained from January to August each year. The only significant period of soil moisture utilization occurs in August to September, even though the region is under intensive cultivation throughout the year. It is also important to note that the balance of average annual surplus rainfall (about 191 mm) includes both surface and subsurface run-off.

Total catchment recharge estimations have rarely been made for the Jaffna limestone due to the absence of relevant data. For the present study, the estimated volume of recharge was calculated for an area of 185.5 km^2 using estimated values of specific yield and an average increase in groundwater levels of 0.61 m for a few selected wells for the period August to December. This limited approach revealed that assuming a specific yield of 0.18 would furnish an average annual recharge rate for the selected area of 2.0×10^7 m^3 (110 mm a^{-1}). However, this value does not account for the variation in the spatial pattern of recharge in the area, particularly as 25% of the shallow dug wells are located in calcareous sandy and gravely formations whose porosity varies from 0.25 to 0.30.

Field and laboratory methods

For the present study, carried out between 1997 and 1998, seven hydrochemical parameters (chloride, total hardness, electrical conductivity (EC), pH, nitrate, sulphate and fluoride) were

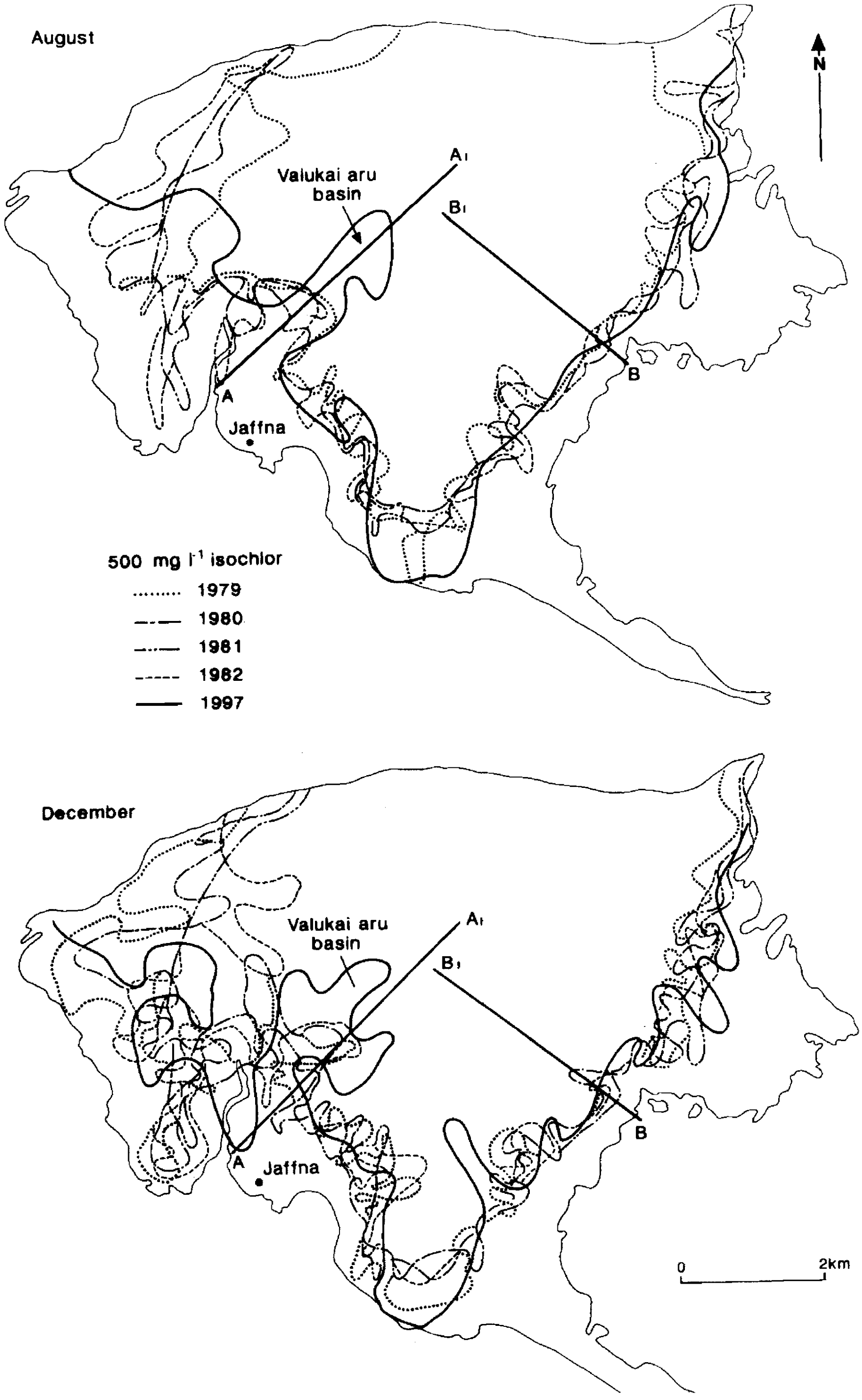

Fig. 7. Spatial distribution of groundwater chloride showing the 500 mg l^{-1} Cl^{-} contour for the years 1979 to 1982 and for 1997 for both August and December.

determined. Two water quality parameters (chloride and total hardness) are discussed in detail since there is a large number of analyses available, particularly for the period 1979 to 1982 (based on secondary data) and for 1997.

Systematic sampling using a bailer was undertaken at 176 locations during both the dry and wet seasons. Water levels in the sample wells were also recorded for both seasons. Rainfall and temperature data were obtained from the Sri Lanka Meteorology Department for the period 1971–1991 and 1971–1981, respectively. Additionally, rainfall and temperature readings for 1997–1998 were recorded at a single station (University of Jaffna). The tidal variation of the Jaffna lagoon was also measured during the period of this study. A questionnaire was distributed to well owners to obtain information on well use and a qualitative appraisal of water quality.

The analytical work was carried out in three different institutions (University of Jaffna, University of Peradeniya and National Water Supply and Drainage Board). The determination of chloride, total hardness, pH and EC (at 25°C) was completed within 48 hours of sample collection. Chloride was determined by silver nitrate precipitation. Additional chloride measurements were made using an ion specific electrode and a reference electrode. Fluoride was determined using a fluoride ion specific electrode and reference electrode. Water hardness due to Ca^{2+} and Mg^{2+} was estimated by titration with standard EDTA using Eriochrome Black T indicator.

Results and discussion

Electrical conductivity and pH

Electrical conductivity values for groundwaters in the study area range from 300 to >22 000 µS cm^{-1}, with the higher values being found in coastal regions and inland areas under intensive agriculture. All measured groundwaters in the region have pH values above 7.0 reflecting the alkaline nature of the limestone aquifer.

Chloride

The geographical setting and geological environment play a major role in determining the distribution of chloride in groundwater in the study area. Chloride concentrations are very high in the sandy calcareous formations of the coastal regions, increasing from 500 mg l^{-1} (the WHO permissible level for chloride) to >4000 mg l^{-1}. The 500 mg l^{-1} Cl^- isochlors for the years 1979 to 1982 and for 1997, for both August and December, are shown in Figure 7 and reveal a number of important features regarding the spatial variation of groundwater chloride: areas under high salinity (>500 mg l^{-1} Cl^-) are confined to the coastal regions; the 500 mg l^{-1} Cl^- contour shows an irregular, meandering spatial variation, both for the dry and wet seasons; and in the Valukai aru area, the 500 mg l^{-1} Cl^- contour expanded significantly in 1997.

The pattern of chloride concentration is a clear indication of seawater intrusion. Concentrations as high as 20 000–30 000 mg l^{-1} in some selected coastal locations provide categorical evidence of seawater intrusion. A noticeable feature in the areas of high chloride concentration is the influence of fracture zones and lineaments (Fig. 7). For example, the lineament feature of the Valukai aru region always presents a linear pattern of high chloride concentration.

Table 1. *Temporal variation in area of groundwater chloride zones*

Year	Chloride zone: Area in km² 500–1000 mg l^{-1}	>2000 mg l^{-1}	Total area in km² >500 mg l^{-1}
August			
1979	47.8	59.0	155.0
1980	21.8	64.8	129.8
1981	39.1	52.4	199.5
1982	–	–	114.4
1997	53.6	46.9	122.9
December			
1979	29.3	47.5	108.4
1980	–	64.4	132.0
1981	25.8	86.0	134.0
1982	19.1	64.9	123.7
1997	42.1	45.7	112.7

Previous studies have suggested that the areas experiencing high salinity have increased since 1979 (Elankumaran 1994). To test this assumption, areas occupied by different salinity levels (chloride zones) were measured for the period from 1979 to 1982 and for 1997 using Figure 7. Results are given in Table 1, it should be noted that the number of wells studied in 1997 (176 wells) was much smaller than the number of wells studied in the period 1979 to 1982 (543 wells). Therefore, the data given in Table 1 should be treated with caution. In general, the extent of the chloride levels in the range 500–1000 mg l^{-1} and >2000 mg l^{-1} is much less or

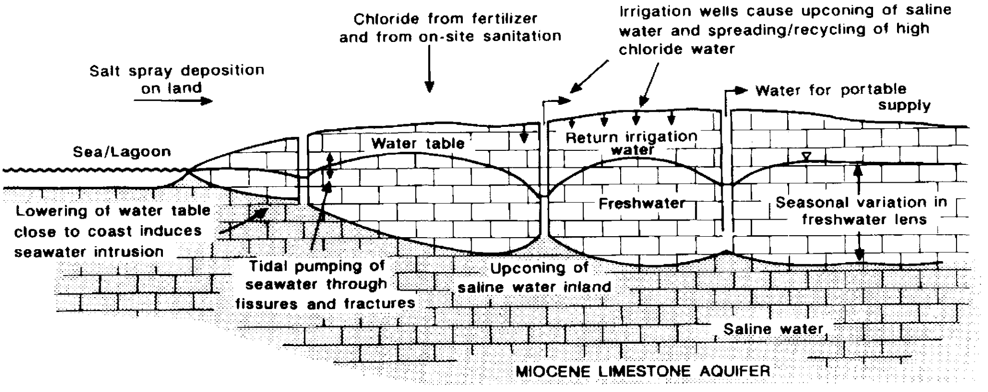

Fig. 8. Conceptual model of the factors controlling the sources and distribution of saline groundwater in the Miocene limestone aquifer of the Jaffna Peninsula.

shows a decline in the wet season (December) compared to the dry season (August). The data also reveal that the total area experiencing groundwater salinity has fluctuated during this period.

The total rainfall data for the corresponding years do not indicate any significant correlation with either the spatial variation of the 500 mg l^{-1} chloride contour or the extent of the areas experiencing saline conditions. A number of factors can be cited that control the chloride pattern, including: changing low and high tides of the lagoons that surround the study area; variation in the thickness of the freshwater lens before and after the inter-monsoonal and the north-east monsoonal rains; changes in the amount and extent of salt spray derived from the surrounding seas/lagoons; pattern of fertilizer inputs on cultivated lands; over-abstraction of groundwater leading to upconing of the saline/freshwater interface and saline intrusion; lineament and fracture position; and improper positioning of latrines.

Figure 8 provides a conceptual illustration of these factors, although whilst each depends to some extent on the location and use of any particular area of land, it is difficult to distinguish between processes due to a lack of data.

In contrast, a gradual increase in chloride concentration with seasonal rainfall has been identified. Figure 9 shows plots of average chloride concentration in the study area against monthly rainfall for the period 1980–1982. Also shown is a well hydrograph for Jaffna (well number 270). Figure 9 reveals a gradual increase in groundwater chloride concentration during

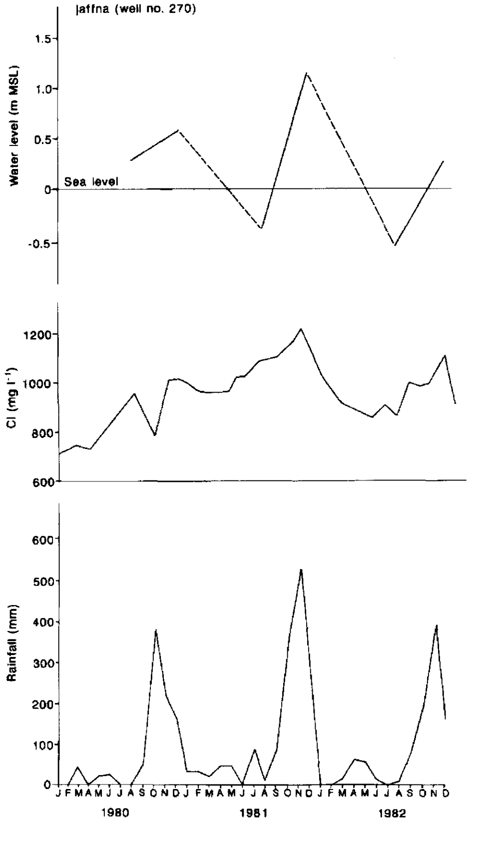

Fig. 9. Relationship between the average monthly rainfall, groundwater level at Jaffna and average chloride concentrations (1980–1982).

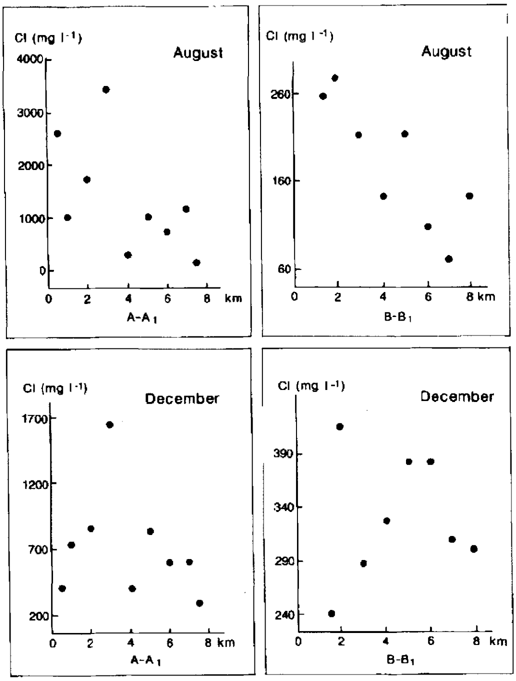

Fig. 10. Graphs showing the relation between distance inland from the coast and chloride concentration for sections A - A_1 and B - B_1 in August and December. The lines of the sections are shown in the Fig. 7.

the dry season, when the groundwater level is near to or below sea level, with the maximum concentration reached soon after the rains commence, followed by a rapid decrease once the rains cease.

In the study area, and as might be expected, the distance inland versus the chloride concentration should maintain a negative correlation as mentioned by Puveneswaran (1986). Figure 10 shows two selected profiles. Profile A-A_1, which includes the Valukai aru basin, shows a weak negative correlation ($r = -0.57$) during the dry season but no correlation during the wet season. In contrast, profile B-B_1 crosses an area that is not influenced by any lineaments. This profile shows a stronger negative correlation between distance inland and chloride concentration ($r = -0.83$) during the dry season, but again shows no trend in December.

Figure 11 shows histograms of chloride levels versus land-use patterns in the study area in August and December for 1979 and 1997. Six land-use types are shown and the histograms suggest that chloride concentrations are relatively low in built-up areas, scrub land, homestead areas, and coconut plantations, while the coastal marsh and barren lands have relatively high chloride levels. As expected, some built-up areas in the coastal zone have higher chloride levels. The irregular chloride distribution in areas under paddy cultivation may be related to the location of these areas. Paddy is cultivated mostly in the coastal region but is also cultivated in some low-lying inland areas. A significant contributory factor to the high levels of chloride in the cultivated land areas is the extensive extraction of groundwater in support of cultivation (Arumugam 1969; Nandakumar 1983) that has caused the lowering of groundwater levels and a rise in the saline water body.

Table 2. *Table of average chloride concentrations identified by cluster analysis for 1983 and 1997*

	Cluster	Number	Dry season (mg l^{-1})	Wet season (mg l^{-1})
1983	A	16	208	289
(previous	B	11	252	254
study)	C	7	348	404
	D	6	793	513
	E	5	822	685
	F	4	189	263
	G	Not reported	528	854
	H	Not reported	625	547
1997	A	70	190	226
(this	B	7	471	238
study)	C	20	375	506
	D	23	716	571
	E	8	1673	605
	F	15	961	1870
	G	7	2906	662
	H	13	2515	3229
	I	4	5096	4718

The patterns of groundwater chloride concentration inferred on the basis of cluster analysis techniques are shown in Figure 12, with the average chloride concentration for each identified cluster shown in Table 2. Elankumaran (1994) applied the cluster analysis method to study the pattern of chloride and total hardness in the Valigamam region for the years 1979, 1981 and 1983, using data from the Water Resources Board (Jaffna). The clusters labelled A, B and C in Figure 12 for 1983 were considered as zones with chloride concentrations below the WHO permissible limit of 500 mg l^{-1}, although some variation is observed between dry and wet seasons. Elankumaran (1994) suggested that the area affected by chloride has varied every year and therefore the clusters that contain good quality water have been shrinking since

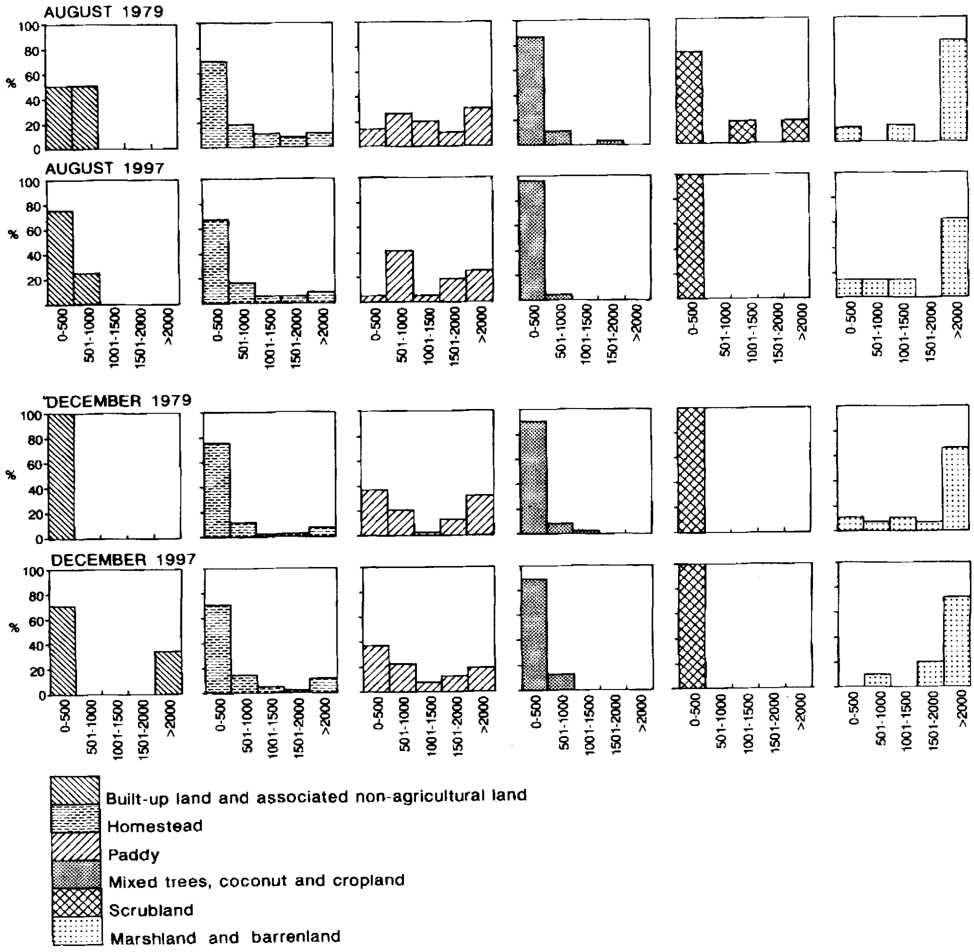

Fig. 11. Histograms showing the relation between land-use pattern and chloride concentrations (1979–1997 August and December).

1979. It is also evident in Figure 12 that the clusters are probably related to the heterogeneity of the limestone aquifer that causes different responses to recharge events, even in wells only 10 m apart.

The cluster analysis performed using data from the present study shows a more complex pattern to that suggested by Elankumaran (1994) for 1983, based on a similar set of site locations. In 1983, the concentration of chloride was higher after the rains when compared to the dry season except in clusters B, D, E, G and I. Higher chloride concentrations were observed in the remaining clusters. Clusters E–I in the 1997 study show a range of chloride concentrations from 961 to 5096 mg l^{-1} (dry season values) that are mainly located in some of the coastal areas in regions of intensified cultivation. Overall, the present study shows no consistent or regular pattern in the extent of groundwater salinity, but there is an apparent decrease in the saline areas by as much two-thirds compared with the earlier studies. In contrast, in the Valukai aru region, there has been an increase of 55% in the area occupied by saline groundwater between 1982 and 1997.

One reason for the observed differences in the spatial distribution of groundwater chloride is the internal migration of people that occurred between 1983 to 1996 as a direct result of the

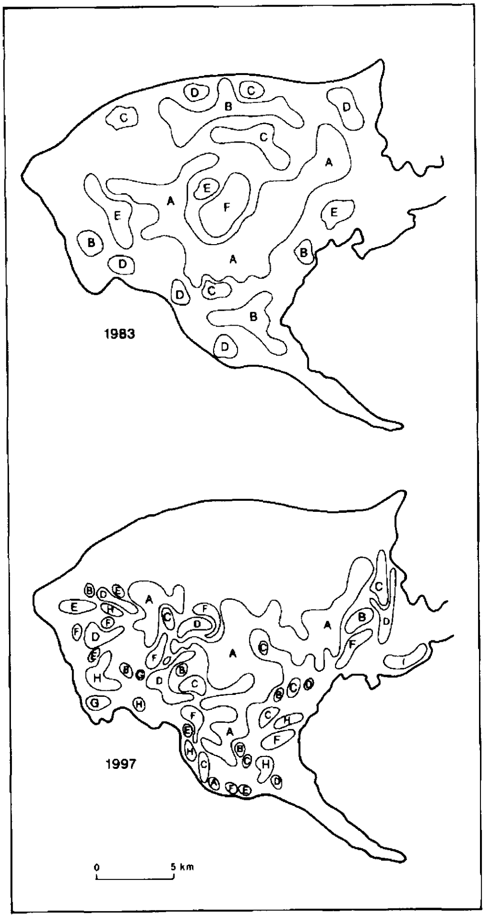

Fig. 12. Pattern of groundwater chloride concentration inferred on the basis of cluster analysis (1983 and 1997 August). See Table 2 for average chloride concentration for each cluster.

political and socio-economic situations. The population density of the Valigamam region underwent a vast change from approximately 4.64 million people in 1981 and 4.86 million in 1993, to 2.42 million in 1997. The population of the northern and north-western parts of the region experienced a sharp decline from about 48 000 to 35 000 in the Valigamam West division and 72 000 to 4600 in the Valigamam North division. These demographic changes may have improved the hydrogeological environment in the northern and north-western coastal areas as reflected in a decline in the total salinity of the area, but the southern area close to the Valukai aru region, which has become densely populated due to internal migration and intensified cultivation, has experienced a deterioration in groundwater quality. The situation was different in 1995 owing to the mass evacuation of people from the entire Valigamam region, a situation that prevailed until the latter part of 1996. Interestingly, even though the population was reduced to almost zero for about a year, there was no improvement in the saline distribution. This is due to the speed with which negative groundwater level elevations were again achieved once pumping restarted and indicates a responsive aquifer, although without more pumping and recharge data it is difficult to determine exactly how responsive.

Total hardness

The spatial pattern of total hardness in groundwaters in the study area, as elsewhere in the Jaffna Peninsula, is related to the hydrochemistry of the limestone aquifer. The distribution of total hardness and its relationship with land use is very similar to the trends observed for chloride.

Table 3. *Temporal variation in area of groundwater total hardness zones*

Year	Total hardness zone		
	Area in km^2		Total area in km^2
	500–1000 mg l^{-1} as $CaCO_3$	>2000 mg l^{-1} as $CaCO_3$	>500 mg l^{-1} as $CaCO_3$
August			
1979	55.0	112.4	123.5
1980	39.2	50.8	110.9
1981	26.1	62.5	122.0
1982	–	–	–
1997	–	–	101.5
December			
1979	33.9	29.6	95.3
1980	37.2	50.5	117.1
1981	25.3	45.3	166.7
1982	35.2	56.5	119.3
1997	47.8	–	100.2

Table 3 shows the extent of areas with total hardness between 501–1000 and >2000 mg l^{-1} $CaCO_3$ for the period 1979–1982 and in 1997. The temporal variation of the two selected total hardness zones is again similar to that shown for chloride (Table 1). Bearing in mind that the data are limited for the years 1982 and 1997, they suggest a gradual expansion of the area with total hardness greater than 500 mg l^{-1} as $CaCO_3$

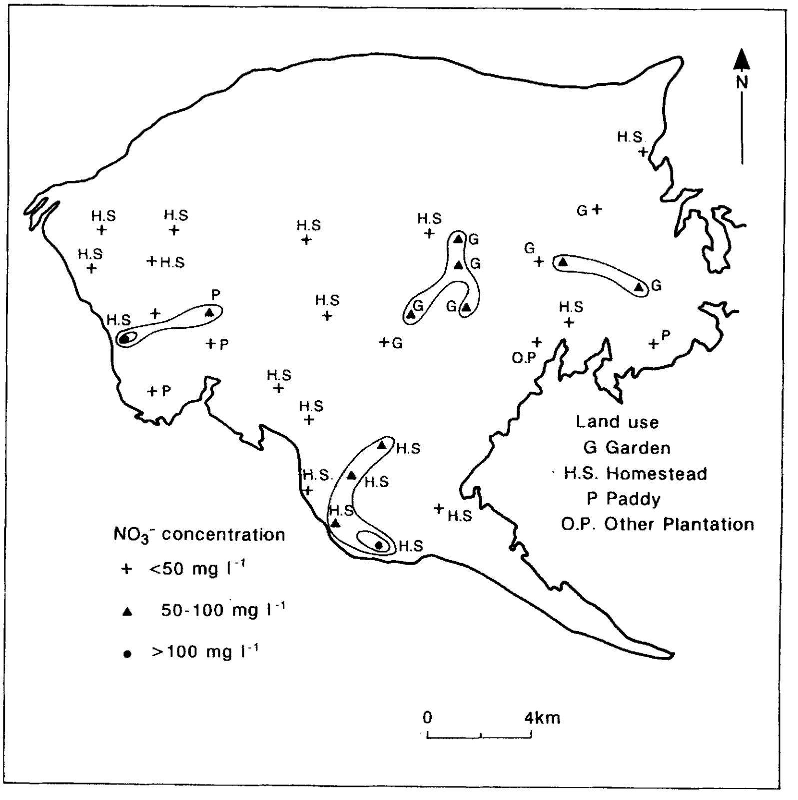

Fig. 13. Concentration of groundwater nitrate in selected locations of the study area for February 1998.

during the wet season (December). A similar trend is seen in the >2000 mg l^{-1} $CaCO_3$ total hardness range. However, in the dry season (August), the 500–1000 and >2000 mg l^{-1} $CaCO_3$ zones show gradual reductions in area. The observed temporary expansion in the total hardness zones shortly after rainfall appears to match expansion in the areas of corresponding chloride concentrations.

Nitrate, sulphate and fluoride

The number of nitrate analyses (35) carried out in the present study is insufficient to properly describe the spatial distribution of groundwater nitrate in the area. A summary of the nitrate concentration data is shown in Figure 13 and it is apparent that the distribution of results is dependent on the source of nitrate, in particular the application of artificial fertilizers and the disposal of human wastes. Nitrate concentrations, particularly in selected agricultural and urban wells, reach values of more than 100 mg l^{-1} NO_3^-. The range of nitrate concentrations is <8 to >165 mg l^{-1} NO_3^- with a mean value of 25 mg l^{-1} NO_3^-.

Previous studies have shown very high levels of nitrate in groundwater in the Jaffna Peninsula (Gunasekaram 1983; Maheswaran & Mahalingam 1983), sometimes up to twice the WHO (1984) standard of 45 mg l^{-1} NO_3^-. In recent years intensive agricultural practices have increased in response to population growth and have resulted in very high inputs of artificial and natural fertilizers, with excessive amounts of manure applied to agricultural land in rotation. Inputs are always above crop requirements, resulting in leaching of the excess to groundwater (Navarathnarajah 1994). In the future, attention should be given to more sustainable agricultural practices that limit this unnecessary loss of nitrate.

Another factor responsible for high nitrate concentrations is the improper planning of soakaway pits and dug wells (Gunasekaram 1983). Distances between latrine pits and dug wells are not maintained as recommended, particularly in highly populated urban areas (Table 4). The distance chosen depends on the site geology and more importantly on the soil type. The Jaffna Municipal Authority recommends a minimum separation of 7.5 m, reflecting a pragmatic approach to the siting of latrine pits in the densely populated coastal areas.

Table 4. *Distances between pit latrines and dug wells for two regions in the Jaffna Peninsula*

1990 Jaffna municipal area		1997 Valigamam area	
Distance (m)	Percentage of dug wells	Distance (m)	Percentage of dug wells
< 1.5	5.7	< 10	13.6
1.6–3.0	8.0	10.1–20.0	48.2
3.1–4.5	5.7	> 20.1	38.2
4.6–6.0	6.8	–	–
> 6.1	73.5	–	–

The depths of dug wells in the study area are generally more than 4.0 m, except in areas underlain by sandy formations, and have a shallow lining. The shorter the length of lining the more likely are surface pollutants derived from agricultural and urban inputs to enter the abstracted groundwater (Table 5). In the present study, a single well in Jaffna town demonstrated a high nitrate level (115 mg l^{-1} NO_3) but all the other locations in the town showed nitrate levels below the WHO standard. Although the number of samples collected in this study was limited, the current situation may be interpreted in a positive way given that the reduction in the population density of the Jaffna division from about 6000 inhabitants km^{-2} in 1981 to 1800 inhabitants km^{-2} in 1996 may help reduce the threat of groundwater contamination from pit latrines.

Table 5. *Length of lining in dug wells of the Valigamam region, Jaffna Peninsula*

Lining (m)	Percentage of wells
< 1.0	7.4
1.1–3.0	41.5
> 3.1	38.5
Damaged	12.6

The same limited number of analyses of water samples for sulphate provided values in the range 1.0–1500 mg l^{-1} SO_4^{2-}. The higher values are observed near the coastal regions and are related to seawater intrusion. Groundwater data for fluoride (35 samples) showed that concentrations of this water quality parameter are low, with less than 1 mg l^{-1} F^- measured in 95% of the samples. This is a result of solubility controls causing calcium fluoride precipitation.

Conclusions

The water resources of the Valigamam region of the Jaffna Peninsula depend totally on rainfall recharge to the Miocene limestone aquifer. The study described here confirms previous findings that with respect to chloride and hardness, the quality of groundwater in parts of the Jaffna Peninsula, including the Valigamam region, is poor and deteriorating. Generally speaking, the levels of chloride, total hardness, nitrate and sulphate are high, and the spatial distribution pattern of these parameters has altered as a result of changes in the demography of the region. Human activities, in the form of adverse agricultural practices and careless waste disposal, have compounded the situation over the years. It is imperative that future work in the region should focus on combining groundwater management and sustainable agricultural practice.

A number of measures have or can be implemented to control or reduce the problems of chloride and nitrate contamination of groundwater. To maintain satisfactory levels of chloride, an important scheme was launched in 1952 by the Department of Irrigation to convert the lagoons into freshwater bodies by flushing out salts (Navaratnarajah 1994). This scheme was completed in the early 1970s and the lagoons were recognized to contain freshwater bodies. Farmers who cultivated land adjoining the lagoons derived the benefits, but poor maintenance of the scheme resulted in a return to the previous adverse conditions in the lagoons and adjacent areas. Other suggested measures include augmenting rainfall recharge by natural or artificial means, and the physical control of seawater intrusion by installing artificial subsurface barriers in coastal areas (Nandakumar 1994). Restrictions on pumping rates in existing and new wells should also be considered.

Lastly, and in common with many areas of the world, local educational programmes are required to strengthen public awareness of the reasons for the poor quality and deteriorating nature of groundwater in the Jaffna Peninsula.

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References

ARUMUGAM, S. 1969. *Water Resources of Ceylon, its Utilisation and Development*. Water Resources Board, Colombo.

ARUMUGAM, S. 1970. Development of ground water and its exploitation in the Jaffna Peninsula. *Transactions of the Institute of Engineers, Ceylon*, **1**, 31–62.

BALENDRAN, V. S., SIRIMANNE, C. H. I. & ARUMUGAM, S. 1968. *Ground Water Resources of the Jaffna Peninsula*. Water Resources Board, Colombo.

CANTWELL, T., BROWN, T. E. & MATHEWS, D. G. 1978. Petroleum geology of the northwest offshore area of Sri Lanka. *Proceedings of the Seapex Conference*, Singapore, 1978.

CHRISTENSEN, H. & DHARMAGUNAWARDHANE, H. A. 1986. *Behaviour of some chemical parameters in tube well water in Matale and Polonnaruwa districts*. Sri Lanka Association for the Advancement of Science, 25–43.

COORAY, P. G. 1984. *An Introduction to the Geology of Sri Lanka (Ceylon). 2nd revised ed.* National Museums Sri Lanka, Colombo, 126–269.

ELANKUMARAN, C. 1994. *Ground Water Patterns of Valigamam Region*. University of Jaffna, Gunesekaran.

GUNESEKARAM, T. 1983. *Ground water contamination and case studies in Jaffna Peninsula, Sri Lanka*. Global Engineering Technology Services, Jaffna.

MAHESWARAN, R. & MAHALINGAM, S. 1983. Nitrate - nitrogen content of well water and soil from selected areas in the Jaffna Peninsula. *Journal of National Scientific Council, Sri Lanka*, **II - 1**, 269–275.

NANDAKUMAR, V. 1983. *Natural Environment and Ground Water in the Jaffna Peninsula, Sri Lanka*. Tsukuba, Japan.

NANDAKUMAR, V. 1994. *Groundwater contamination in the Jaffna Peninsula*. University of Tsukuba, Ibaraki, **305**, 155–164.

NAVARATHNARAJAH, V. 1994. Water problems in the Jaffna Peninsula. *20th WEDC Conference in Affordable Water Supply and Sanitation*, 1994, 191–193.

PUVENESWARAN, K. M. 1986. Spatial temporal variation and the human dimensions of groundwater of Jaffna Peninsula. *Beitrage zur Hydrologie*, **5**, 827-845.

RAJESWARAN, S. T. B., ROBERT, G., RAJASOORIYAR, L. D. 1993. The evolution and the morphological structure of the Jaffna Peninsula. *Sinthanai*, **5**, 58–65.

YOGARAJAH, K. 1991. *De-silting of ponds*. Irrigation Office, Jaffna Division.

WORLD HEALTH ORGANISATION. 1984. *Guidelines for Drinking Water Quality. Vol. I: Recommendations*. WHO, Geneva.