WATER QUALITY OF SOME WELLS IN JAFFNA AND KILINOCHCHI WITH SPECIAL REFERENCE TO NITRATE POLLUTION

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ABSTRACT

Water samples from 65 wells in the Jaffna and Kilinochchi districts were analysed for pH, EC_w, Na, K, Ca, Mg, P and NO_3—N. About 65% of the wells in the Jaffna peninsula had high salinity water; in the Islands more than 80% of the wells were very high in salinity. Most wells in Kilinochchi however, were medium in salinity. With respect to Na—hazard most wells fell into the low to medium—Na water categories. Potassium contents were low to medium in the wells of Jaffna peninsula and Kilinochchi, but very high in the Islands. Phosphorus levels were extremely low in the wells tested. Nitrate—N in majority of farm wells were much higher than the permissible level of 11.3 ppm N stipulated by WHO for drinking water. Domestic wells on the other hand had low NO_3^- levels. It appears that high NO_3^- content in well-waters is associated with the intensive agriculture practised in the Jaffna peninsula. Measures to minimize this increase are discussed. Owing to the substantial amounts of N and K in the well-waters there are possibilities of adjusting the amounts of these nutrients added as fertilizers to crops grown in these areas.

KEY WORDS: Groundwater quality, Nitrate pollution, Potassium content, Salinity, Sodium hazard, Well-water quality

INTRODUCTION

The Jaffna peninsula lies in the extreme north of Sri Lanka and occupies an area of 870 sq. km. It has a mean annual rainfall of 1,000—1,200 mm, most of which occurs during the north-east monsoon (October to December). It is almost entirely underlain by limestones of the Miocene period and their highly permeable cavernous and karst structures form good underground reservoirs to absorb and store infiltrating water. In the peninsula, water for human consumption and irrigated agriculture is provided through open shallow-wells (large-diameter hand-dug type) sunk in the limestone aquifers which are recharged during the rainy season. Estimates of the number of shallow-wells vary from 10,000 to 84,000 (Foster, 1976).

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The major soils in the peninsula are the Calcic Red-Yellow Latosols (De Alwis and Panabokke, 1972). The calcic red latosols which predominate are shallow, fine-textured and well-drained with very rapid infiltration rate. In the islands of the Jaffna peninsula, soils on Recent Marine Calcareous Sediments occur (De Alwis and Panabokke, 1972).

In Kilinochchi district moderately fine-textured Red-Yellow Latosols and Alluvial soils of variable drainage and texture are the major soil groups (De Alwis and Panabokke, 1972). The red latosols are very deep and excessively drained while the yellow latosols are also very deep but imperfectly to poorly drained.

Crops such as chilli, onion, potato, tobacco and vegetables are intensively cultivated in the well-drained soils of the Jaffna peninsula. High levels of organic manures (cattle manure, goat manure and green manure), inorganic fertilizers and agrochemicals are applied to these high value crops. In early times (before 1960) water was drawn from wells using traditional methods of water lifting (e. g. well-sweeps). Presently, however most wells are equipped with small electric or diesel-engined surface suction-lift pumps. Consequently, there is a tendency to use more water for crops than necessary. In the less permeable and saline soils, rice is grown under rainfed conditions during the maha season.

Chilli, onion and vegetables are grown in the red latosols of the Kilinochchi district under irrigation. Water for irrigation is obtained from wells are which generally deeper than those in the Jaffna peninsula. The cultivation intensity and organic manure use are less compared to that practised in the calcic red-yellow latosols. In the alluvial soils, rice is grown largely under rainfed condition although in certain areas supplementary irrigation is available from tanks (e. g. Iranamadu).

In recent times concern has been expressed about the increase in salinity of well-waters due to over-extraction and nitrate pollution through continuous and liberal use of organic manures and inorganic fertilizers. However, no systematic monitoring of well-waters has been undertaken in the Jaffna peninsula to conclude whether such concerns are justified. In 1981, a study was carried out in which water samples from a number of selected wells in the Jaffna peninsula were monitored for nitrate content, salinity and some important chemical constituents. Well-waters from Kilinochchi were also analysed for these parameters. This paper discusses the results of this study.

MATERIALS AND METHODS

Collection of well-water samples

Water samples from shallow-wells were collected over a depth of about 30 cm below the water surface using a plastic bucket. Whenever the water surface had floating scum or algae, these were skimmed before collecting the samples. In the case of tube-wells, pumps were started and samples taken as water issues from the outlet. Each sample was poured into a polyethylene bottle after rinsing it several times with the water to be sampled and securely sealed. The samples were then taken to the laboratory at the Central Agricultural Research Institute, Gannoruwa as quickly as possible for analysis. At the time of collection, depth of well was measured and recorded.

Monthly water samples were collected from 23 shallow-wells in the Jaffna peninsula beginning March 1981 for a period of 12 continuous months. One set of samples from wells in the islands off the Jaffna peninsula, hereafter referred to as 'Islands', was obtained in April 1982. A set of samples from the shallow and tube-wells in Mulankavil, Thiruwaiaru and Mirusuvil was also collected in June 1982. The sampling sites and number of wells sampled at each site are shown in Fig. 1 (map).

Analysis

On reaching the laboratory the water was filtered and filtrate used for analysis. Where samples have to be stored for long periods, chloroform was added to prevent any fungal growth.

pH with a glass electrode and electrical conductivity (EC_w) using a Mullard conductivity bridge were determined as soon as the water samples reached the laboratory. Sodium and K were determined using an Eppendorf flame photometer. Calcium and Mg were determined by EDTA titration using HHSNNA and Eriochrome Black T as indicators. Phosphorus was determined colorimetrically by the molybdenum blue method using ascorbic acid (Watanabe and Olsen, 1965). Nitrate was determined colorimetrically by the brucine method (Taras, 1958).

RESULTS AND DISCUSSION

Well-waters for analysis were taken from three broad areas namely the Jaffna peninsula, Islands and Kilinochchi district. The analysis of the samples from these areas are given in Tables 1, 2 and 3.

pH and Electrical conductivity (EC_W)

The pH values of well-waters in the Jaffna peninsula were around 7 (Table 1); in the Kilinochchi area pH varied from 5.9 to 8.4. High values for pH were recorded in Mulankavil for both shallow and tube-wells (Table 3). According to Ayers and Westcot (1985) normal pH range for irrigation water is from 6.5 to 8.4. Amarasiri (1965) found the pH of some rice irrigation waters used by farms and experiment stations of the Sri Lanka Department of Agriculture in the wet and dry zones to range from 5.7 to 8.1. He also observed an inverse relationship between pH of irrigation water and degree of rainfall. In a similar study involving major irrigation tanks of Sri Lanka which are all located in the dry zone, pH values were found to be around 8 (Amarasiri, 1973).

Irrigation water contains salts in relatively small but significant amounts. The salts originate from dissolution or weathering of rocks and soil. When irrigation water is applied to the soil, the salts remain behind in the soil as water evaporates or is used by the crops. The extent to which salts accumulate in the soil will depend on the irrigation water quality, irrigation management and drainage. If the soil becomes saline then crop yields are adversely affected. Salt concentration in water is usually expressed in terms of electrical conductivity (EC_W), which can be readily and precisely determined. The United States Department of Agriculture (USDA) (1954) has classified irrigation waters according to electrical conductivity as follows:

EC_W (*dS/m*)	*Class*
0 — 0.25	low salinity water
0.25 — 0.75	medium salinity water
0.75 — 2.25	high salinity water
> 2.25	very high salinity water

On this basis about 30% of the wells sampled in the Jaffna peninsula had high salinity water while 65% of the wells were very high in salinity (Table 1). In the Islands all wells except one, had very high salinity water. In fact, more than 80% of the wells sampled had EC_w values very much higher than the very high limit of 2.25 dS/m (Table 2). On the other hand, both shallow and tube-wells in the Kilinochchi district had medium salinity water, except 3 wells in Mulankavil which had high to very high salinity waters (Table 3). It is relevant to report that 4 tube-wells located in the grumusols of Murunkan (Mannar district) had EC_W values ranging from 1.20 to 2.85 dS/m (Jeganathan and Pain, 1982). Ayers and Westcot (1985) have stipulated that there is no restriction on the use of irrigation water having a EC_W of 0.7 dS/m. On the other hand, a severe restriction is placed on irrigation waters having EC_W values over 3 dS/m.

Despite the high salinity water of the wells, crops such as chilli, onion and tobacco grown under irrigation give good yields and seldom show any adverse effects of salinity. This could be attributed to the high infiltration rates of the well-drained calcic latosols. It is also likely that these crops have a fair degree of salt-tolerance. Another reason could be the flood irrigation practised whereby water is applied in excess which is quickly drained leading to considerable leaching (Richards, 1954).

Sodium Hazard

Irrigation with high sodium water can lead to the formation of sodic soils. These soils have an unsatisfactory physical condition which makes cultivation difficult. Sodium can also be toxic to many plants. The adverse effects of Na are considerably reduced if the irrigation water has a high proportion of Ca and Mg. According to Richards (1954), Sodium Adsorption Ratio (SAR) is a useful index for designating the Na hazard of waters used for irrigation. It is defined as follows:

$$SAR = \frac{Na}{\sqrt{[\frac{1}{2}(Ca+Mg)]}}$$

where concentrations of Na, Ca and Mg are expressed in me/l.

The classification of irrigation waters with respect to SAR is as follows:

SAR	*Class*
0—10	low-Na water
10—18	medium-Na water
18—26	high-Na water
>26	very high-Na water

In the Jaffna peninsula the SAR values of well-waters were very much below 10 except for a well at Nunavil (Table 1). Thus, these well-waters belong to the class of low-Na water. Both shallow and tube well-waters in the Kilinochchi district also belong to this class except three wells in Mulankavil which fell into the medium-Na category (Table 3). Of the wells sampled in the Islands only 35% had low-Na water; the remaining wells fell into the medium-Na class (Table 2).

Sodium content of well-waters in the Jaffna peninsula ranged from 0.4 to 19.6 me/l. A domestic well at Nunavil however, had 43.5 me/l (Table 1). Except for three wells in Mulankavil, the well-waters of the Kilinochchi district had relatively lower Na content (1.6 to 8.7 me/l) (Table 3). In general, the well-waters of the Islands contained very high levels of Na (Table 2). The Na values reported by Amarasiri (1965; 1973) for irrigation waters were much lower than these values. Ayers and Westcot (1985) reported that the usual range for Na in irrigation water is 0—40 me/l.

Calcium and Magnesium

Calcium and Mg content in the Jaffna peninsula well-waters ranged from 1.3 to 22.3 me/l and 0.2 to 9.7 me/l respectively (Table 1). In the well-waters of Islands, Ca values varied from 2.1 to 32.9 me/l while Mg values were from 0.4 to 29.8 me/l. One domestic well from Pungudutivu recorded a very high value of 64.1 me/l for Mg (Table 2). Calcium and Mg values for well-waters in the Kilinochchi district were lower, being 0.6 to 7.1 me/l for Ca and 0.3 to 3.6 me/l for Mg. Usual range found in irrigation waters is 0—20 me/l for Ca and 0—5 me/l for Mg (Ayers and Westcot, 1985).

Irrigation of soils with Mg dominated water ($Ca/Mg < 1$) sometimes results in low productivity possibly due to Mg induced Ca deficiency (Ayers and Westcot, 1985). Magnesium dominated only in a few wells in Jaffna peninsula (3 wells), Islands (7 wells) and Kilinochchi district (3 wells).

Irrigation waters from tanks and streams had much lower Ca and Mg contents (Amarasiri, 1965; 1973).

Potassium

Potassium levels in well-waters were generally low to medium (0.1 to 0.9 me/l) in the Jaffna peninsula and Kilinochchi district (Tables 1 & 3) and very high (0.4 to 2.1 me/l) in the Islands (Table 2). One well at Pungudutivu had a value of 5.1 me K/l. Amarasiri (1965; 1973) reported values ranging from 0.01 to 0.40 me/l for irrigation waters. All these values are outside the usual range of 0—0.05 me/l reported for irrigation waters (Ayers and Westcot, 1985).

Phosphorus

Phosphorus is extremely low in the well-waters (Table 1). In most cases it could not be detected (Table 3). Amarasiri (1965) reported very low levels in rice irrigation waters (< 0.05 mg/l). This is to be expected because movement of any soluble P to groundwater is restricted because of its ready fixation by soil minerals.

Nitrate Nitrogen (NO_3—N)

Water samples in the Jaffna peninsula and the Islands were obtained from both farm and domestic wells. Wells in the farms are largely used for irrigating crops. But in many cases, the water is also used for drinking purposes especially, when the farmers reside within the farms. Farm families who work in their farms also drink water from these wells.

Medical specialists have expressed concern about the undesirable effects of a high nitrate intake on human health and in particular on the health of babies up to about 4 months of age (Russell, 1978). Nitrate itself is not considered toxic, but NO_3^- may be reduced to nitrite (NO_2^-) by bacteria present in the upper gastro-intestinal tract which is then absorbed into the blood stream. Babies below a certain age may be unable to detoxify NO_2^- which combines with haemoglobin and reduces the absorption of oxygen into the blood resulting in a clinical condition called 'methaemoglobinaemia' (cyanosis). An infant suffering from this condition is sometimes referred to as a 'blue baby' although the blue condition may result from other causes. It is also claimed that even for adults, a high NO_3^- intake is undesirable because some of the NO_2^- produced may be converted to nitrosamines causing gastric cancer (Hill *et al.*, 1973). In view of these possibilities, a maximum for nitrate content in drinking water has been stipulated from time to time. The WHO recommended the following standards for drinking water in Europe (Olsen, 1978):

0	—	11.3 mg/l NO_3—N	— — — —	Recommended
11.3	—	22.6 mg/l NO_3—N	— — — —	Acceptable
above	—	22.6 mg/l NO_3—N	— — — —	Not recommended

In USA, a permissible level of no more than 10 mg/l NO_3—N has been established for drinking water (Gervy, 1986).

Olsen (1978) pointed out that the question of what is acceptable nitrate concentration of water is a debatable issue for humans because no reports of methaemoglobinaemia have been made of infants drinking from public water supply systems in the USA. Even recently, it has not been possible to show any relationship between contents above 10 mg/l limit and the incidence of gastric cancer and no statistical connection between NO_3—N contents above 20 mg/l and the incidence of methaemoglobinaemia (Gervy, 1986).

It is also relevant to note that vegetables containing high NO_3^- as a result of excessive use of fertilizers, could also result in the health problems associated with high NO_3^- drinking water (White, 1975).

Of the farm wells sampled in the Jaffna peninsula 21% had waters with NO_3^-N content less than 11.3 mg/l, 31.5% within the range of 11.3 to 22.6 mg/l and 47.5% with values above 22.6 mg/l. Thus 79% of the wells sampled had waters with NO_3—N levels higher than the WHO recommended value of 11.3 mg/l.

An old well at Kopay which irrigated an intensively cropped farm had water containing very high NO_3—N level (41.6 mg/l). But water in a newly dug well situated close to this old well and in a virgin land, had a very low

NO_3—N level (3.8 mg/l). This probably indicates that the aquifers of the two wells are not connected. Two other farm wells at Madduvil and Nunavil had waters containing very low levels of NO_3—N (Table 1). These wells are located on the coastal sandy tracts, where rainfed rice is grown during maha season, with little or no fertilizer addition. The well at Madduvil is used during the yala season to irrigate vegetable crops such as brinjal and pumpkin for which fertilizer use is low.

High NO_3—N values were also recorded in two domestic wells at Thirunelvely (28.1 mg/l) and Kondavil (26.3 mg/l). These are found on the Palaly-Jaffna road and were farm wells earlier. It is interesting to note that the first analysis of NO_3^- in the pumped water supplies from the Kondavil and Thirunelvely sources carried out at the Central Agricultural Research Institute, Gannoruwa in March 1976 gave values of 15 and 23 mg/l NO_3—N respectively (Foster, 1976).

The domestic well-waters were comparatively low in NO_3—N except that of the well at Thirunelvely which belongs to the National Water Supply and Drainage Board and provides drinking water to some parts of the Jaffna town (Table 1). It is important to mention that this well is not very far from the Agricultural Research Station, Thirunelvely where high cropping intensity and regular fertilizer applications are practised.

In Islands, about 50% of the wells had water with NO_3—N content higher than 11.3 mg/l (Table 2). Water in two of the wells had very high levels of NO_3—N (74 and 95 mg/l). The remaining farm and domestic-wells of the Islands had waters of extremely low NO_3—N contents (Table 2). The waters of the shallow and tube-wells of the Kilinochchi district also had very low NO_3—N (Table 3).

Nitrogen in the groundwater is derived from mineralization of soil organic matter, symbiotic and asymbiotic nitrogen fixation, rainfall, fertilizers, animal wastes, green manures, crop residues and sewage effluents. Ammonium fertilizers, and ammonium-forming fertilizers such as urea, when added to upland soils are normally nitrified to nitrates. On the other hand, nitrogen in organic materials undergoes mineralization to NH_4^+ before nitrification. Unlike NH_4^+, K^+ and $H_2PO_4^-$, nitrate (NO_3^-) is not fixed by the soil minerals. Therefore, any excess NO_3^- can easily percolate through soil and reach the groundwater. Thus, use of both inorganic fertilizers and organic manures can contribute to the increase of nitrate in groundwater. However, there is no direct evidence to show that fertilizer application contributes to increase in NO_3^- content of groundwater. In a comprehensive study by the U. S. Salinity Laboratory, it was found that NO_3^- levels in the upper Rio Grande Watershed did not increase despite a many-fold increase of fertilizer—N usage in the adjacent irrigated valley land (Bower and Wilcox, 1969). Similarly, nitrate concentrations did not increase in the majority of 17 British streams studied during the period 1953—1967 despite a substantial increase in fertilizer use during the period (Halliday, 1972). On the other hand, there are reports that NO_3^- levels in groundwater increased following the intensive use of animal wastes and fertilizers (Rodda *et al.*, 1976; Ballance and Olsen, 1980; Gervy, 1986).

The high nitrate levels recorded in well-waters of the Jaffna peninsula's agricultural areas is very likely related to the intensive cultivation practised in that region. It is a well known fact that farmers in this region apply very large amounts of animal wastes, green manures and crop residues in addition to heavy applications of inorganic fertilizers and agrochemicals. Additionally, irrigation from wells is also provided at a higher rate and frequency especially, after the introduction of pumps for lifting water. Water is applied to the crops (chilli, onion, tobacco, vegetables etc) through flood irrigation. In view of the fact that the limestone aquifers are covered by a thin mantle of highly-permeable calcic latosols, rapid movement of any NO_3^- not utilized by crops can reach the aquifers resulting in high NO_3^- levels.

If the top of a well is not constructed to divert surface water away from a well, then NO_3^- can enter the well from above and increase its concentration in the water. In fact, in many of the farm wells sampled, the tops were either not constructed high enough or were badly damaged so that surface water could easily enter the wells during rainy seasons.

In the Jaffna peninsula, there is very little sewering and most domestic effluents are discharged to the ground via septic tanks and cess pits. Nitrate from the sewage effluents can also enter well-water resulting in an increase in its NO_3^- level. There is however, a regulation by the Local Government Bodies that septic tanks, should be constructed far away ($>$15 m) from domestic wells.

That intensive cultivation with high fertilizer and manure use coupled with over-irrigation in these highly permeable soils could lead to high NO_3^- levels in the groundwater is seen from the observation that waters from farm wells had high NO_3^- levels whereas domestic wells had much lower NO_3^- levels. A more convincing indication of the effect of fertilizer use on NO_3^- level can be seen in the well in Kopay dug in a new land to be brought under cultivation, but located adjoining an intensively cultivated area, having a very low NO_3^- content (3.8 mg/l). Wells in rice fields where fertilizer use is marginal also had low NO_3^- content.

Thus, it appears that intensive cultivation coupled with high chemical fertilizer and organic manure use in the Jaffna peninsula may have contributed to the build-up of NO_3^- in well-waters. There are many ways of minimizing build-up of NO_3^- concentration in well-waters. They are:

(1) Levels of fertilizer—N applied should not greatly exceed that necessary for attainable crop yields.

(2) Application of fertilizer—N in several split doses. It would be ideal if these split doses coincide with the times the crop actually needs N.

(3) Use of slow release N-fertilizers.

(4) Use of nitrification inhibiters such as N-Serve.

(5) Cultivation of crops with large volume of roots to capture the nitrates. Stewart *et al.* (1968) reported little accumulation of NO_3^- in soil profiles under the deep-rooted crop alfalfa, suggesting its capability as a 'scavanger' for NO_3^- leached below the normal rooting depth of shallow-rooted crops.

(6) Maintaining a cover crop on the land as much of the time as possible.

(7) Light irrigation because it makes NO_3^- movement very slow thereby keeping it longer within the root zone.

Finally, there should be a programme to monitor NO_3^- levels in selected wells so that timely action could be taken to arrest its build-up in groundwater beyond the recommended level.

Nitrogen and Potassium Supply

Nitrogen

Nitrate-N which is undesirable if it exceeds 11.3 mg/l in drinking water, is essential for crop growth. Therefore, when crops are irrigated with high NO_3— water, it will provide a significant proportion of their N requirement. Consequently, substantial savings in the amount of N fertilizer applied can be made, depending on the NO_3— content of the water.

Based on the amount of water required to irrigate chilli (116 ha. cm) and onion (67 ha. cm) in the calcic red latosols (J. A. Lewis, personal communication, 1982) and a NO_3—N content of 11.3 mg/l, N contribution from well-water would be 131 kg N/ha for chilli and 76 kg N/ha for onion. These are higher than the recommended amounts of 120 kg N/ha for chilli and 40 kg N/ha for onion (Nagarajah, 1986). Since water is applied frequently and in smaller amounts during the growth duration of the crop, its N contribution may not match the needs of the crop. It is also important to note that, of the water applied a portion is lost due to deep percolation. According to J. A. Lewis (Personal communication, 1982) deep percolation losses for onion and chilli crops are 34 and 46 ha.cm respectively. Thus NO_3—N amounting to 38 and 52 kg/ha (at a NO_3—N content of 11.3 mg/l) in farmlands planted to onion and chilli crops respectively can percolate into the groundwater. With high levels of NO_3—N in water, amounts of N available to crops and lost to the groundwater will also be correspondingly high. However, the actual savings in chemical nitrogen fertilizer as a result of contribution from well-water can be determined only from results of field experiments carried out with these crops.

Potassium

As in the case of N, well-water will also provide K to crops. When water has 0.1 me/l, onion and chilli crops can receive 31 and 54 kg K_2O/ha respectively. The recommended rates for these crops are 51.7 (onion) and 101.2 kg K_2O/ha (chilli) (Nagarajah, 1986). Most wells had K contents much higher than 0.1 me/l (Table 1). Unlike NO_3—N, K can be held and fixed by the soil minerals. Therefore, it is not readily lost to groundwater. Thus, substantial amounts of K in the well-water are available to the crops and consequently fertilizer K application can be reduced. Amarasiri (1965) also reported that very large quantities of K are supplied by irrigation waters.

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Table 1. Water analysis of selected wells in the Jaffna peninsula

Site	Depth (m)	pH	EC_W* (dS/m)	SAR	Ca* (me/l)	Mg* (me/l)	Na* (me/l)	K* (me/l)	P* (mg/l)	NO_3-N* (mg/l)
Farm Wells										
Araly	3.0	7.0	3 56	5.6	11.4	7.2	17.2	0.3	0.010	18.0
Atchuvely	3.7	7.1	3.56	6.1	10.9	6.6	18.0	0.3	0.002	14.6
Chankanai	7.7	7.2	1.39	1.1	9.4	1.8	2.5	0.1	0.010	33.0
Chulipuram	4.0	6.9	2.51	2.2	14.0	5.5	6.8	0.2	0.010	11.9
Iyakachchi	2.0	7.4	2.29	0.4	1.3	0.6	0.4	0.2	0.005	12.3
Kaithady	5.3	7.0	5.02	5.1	22.3	7.4	19.6	0.4	0.005	45.2
Karanavai	5.4	7.0	3.56	6.6	9.8	7.2	19.1	0.9	0.005	55.7
Kopay (old well)	8.3	7.1	2.83	3.9	12.7	2.7	10.9	0.1	0.005	41.6
Kopay (new well)	8.7	7.6	0.28	0.4	2.2	0.2	0.4	0.1	0.001	3.8
Madduvil	4.0	7.1	3.56	5.1	14.9	7.0	16.9	0.9	0.002	1.0
Maruthanamadam	7.8	7.4	0.87	1.0	6.4	0.7	1.9	0.1	0.010	25.2
Mirusuvil	8,3	7.4	5 61	2.1	1.8	1.3	2.6	0.2	0.013	13.8
Nunavil	3.5	7.6	5.43	0.8	2.2	3.0	1.3	0.3	0.001	0.6
Pandattarippu	3.2	7.0	2.29	2.2	15.9	4.1	6.9	0.1	0.005	33.2
Puttur	6.2	7.1	0.94	1.9	5.7	1.0	3.3	0.2	0.005	37.3
Puttur (Tidal well)	60.0	7.0	1.12	4.0	3.9	1.3	6.4	0.2	0.005	14.3
Siruppiddy	2.3	7.2	2.26	3.6	11.4	2.7	9.6	0.2	0.020	26.4
Thirunelvely—ARS	10.7	7.2	1.03	1.4	8.3	0.8	2.9	0.1	0.005	28.7
Vasavilan	7.9	6.8	0.83	2.6	3.7	1.1	4.0	0.1	0.005	9.2
Domestic wells										
Araly	3.7	7.3	3.02	5.5	8.3	6.2	14.8	0.2	0.010	1.9
Nunavil	5.3	7.3	5.00	10.9	6.3	9.7	43.5	0.2	0.002	0.2
Tellippalai	8.4	7.0	0.83	2.2	3.7	1.5	3.6	0.3	0.010	9.6
Thirunelvely—MC	12.4	7.0	2.81	5.1	11.6	3.1	13.9	0.1	0.005	30.8

*Average of the 12 monthly samples; ARS = Agricultural Research Station; MC = Municipal Council

Table 2. Water analysis of selected wells in the Islands

Site	Depth (m)	EC_W (dS/m)	SAR	Ca	Mg	Na	K	NO_3-N (mg/l)
				(me/l)				
Farm Wells								
Allaipiddy	4.3	1.76	1.4	8.1	5.1	3.5	0.4	5.0
Analaitivu	2.3	7.63	11.8	31.1	29.8	65.2	1.5	0.2
Delft—1	3.1	8.86	15.0	17.4	15.7	60.9	2.1	0.5
Delft—2	2.5	4.80	14.0	7.1	8.2	38.6	1.1	0.1
Delft—3	2.1	4.43	9.6	11.1	9.4	30.8	0.9	2.0
Karampon	4.8	2.50	14.7	18.5	10.9	56.5	0.8	28.0
Mandaitivu	3.1	5.66	13.2	18.5	12.6	52.2	1.3	32.0
Mankumpan	2.6	1.47	0.3	2.3	0.4	0.4	N.D.	0.5
Nainativu—1	2.5	8.49	12.1	26.4	17.4	56.5	1.3	25.0
Nainativu—2	2.6	7.87	13.6	22.2	17.8	60.9	1.4	12.0
Naranthanai	4.6	2.09	6.6	4.2	3.6	13.0	0.5	1.0
Pungudutivu—1	3.3	10.96	15.2	32.9	20.3	78.3	1.0	95.0
Pungudutivu—2	3.5	6.65	12.7	15.5	12.6	47.8	0.9	18.0
Velanai—1	4.3	3.08	12.9	4.6	3.6	26.1	0.5	7.0
Velanai—2	3.8	3.70	9.4	12.6	5.7	28.3	0.5	74.0
Domestic wells								
Allaipiddy	3.1	2.03	7.1	4.0	2.7	13.0	0.5	0.1
Analaitivu	2.9	3.57	6.2	10.1	8.0	18.6	0.6	0.1
Delft—1	2.2	2.95	7.5	7.3	5.2	18.7	0.5	2.1
Delft—2	2.0	4.55	16.9	2.1	8.4	38.7	1.3	0.1
Mandaitivu	3.4	4.13	15.5	6.7	9.0	43.5	0.9	0.8
Mankumpan	4.1	0.89	1.2	6.5	3.2	2.6	0.5	2.2
Nainativu—1	2.9	6.65	17.1	11.5	10.3	56.5	1.1	0.1
Nainativu—2	2.3	7.87	12.7	19.5	19.9	56.5	1.0	0.1
Naranthanai	5.6	4.10	10.9	4.2	7.3	26.1	0.6	10.0
Pungudutivu	3.7	16.72	32.5	25.2	64.1	217.4	5.1	0.2
Velanai	3.2	3.08	15.7	3.1	4.6	30.9	0.7	3.0

N. D. = not determined

Table 3. Water analyses of selected wells in Kilinochchi district

Site	*Depth* (*m*)	*pH*	EC_W (*dS/m*)	*SAR*	*Ca* (*me/l*)	*Mg* (*me/l*)	*Na* (*me/l*)	*K* (*me/l*)	*P* (*mg/l*)	NO_3^--*N* (*mg/l*)
Kilinochchi—RARC										
Shallow well—1	6.9	7.2	0.43	1.8	2.4	0.3	2.1	0.2	n.d.	0.9
Shallow well—2	8.0	7.2	0.46	1.6	1.8	0.7	1.8	Tr	n.d.	2.6
Tube well—1	21.0	6.4	0.52	1.7	2.4	1.4	2.3	Tr	n.d.	5.1
Tube well—2	21.0	6.2	0.47	2.0	1.8	0.9	2.4	0.1	n.d.	5.1
Tube well—3	18.0	7.0	0.82	2.2	2.8	2.2	3.4	0.1	n.d.	0.1
Tube well—4	19.5	6.7	0.50	1.2	2.6	0.9	1.6	0.1	0.005	2.0
Mulankavil										
Shallow well	9.8	8.4	1.76	14.4	1.4	1.5	17.4	0.2	n.d.	0.6
Tube well—1	30.0	7.5	3.08	12.8	7.1	2.3	27.8	0.3	n.d.	2.3
Tube well—2	36.0	8.1	3.08	18.7	3.1	2.7	32.2	0.3	n.d.	0.3
Tube well—3	33.0	8.0	0.74	1.1	4.2	0.8	1.8	0.1	n.d.	0.9
Paranthan—ARS										
Shallow well	6.4	7.2	1.36	4.8	3.0	3.6	8.7	0.1	n.d.	0.1
Tube well	19.5	7.1	0.86	2.8	3.1	1.5	4.2	0.1	n.d.	0.3
Thiruvaiaru										
Shallow well—1	6.9	5.9	0.30	1.7	0.6	1.5	1.9	0.1	n.d.	1.0
Shallow well—2	7.4	7.2	0.44	1.8	1.4	1.1	2.0	0.2	n.d.	0.9
Shallow well—3	9.3	7.2	0.39	1.6	2.3	0.8	2.0	0.1	n.d.	4.8
Shallow well—4	8.4	6.9	0.48	1.7	2.3	0.7	2.1	0.1	n.d.	0.9

RARC = Regional Agricultural Research Centre; ARS = Agricultural Research Station; n.d. = not detected; Tr = traces

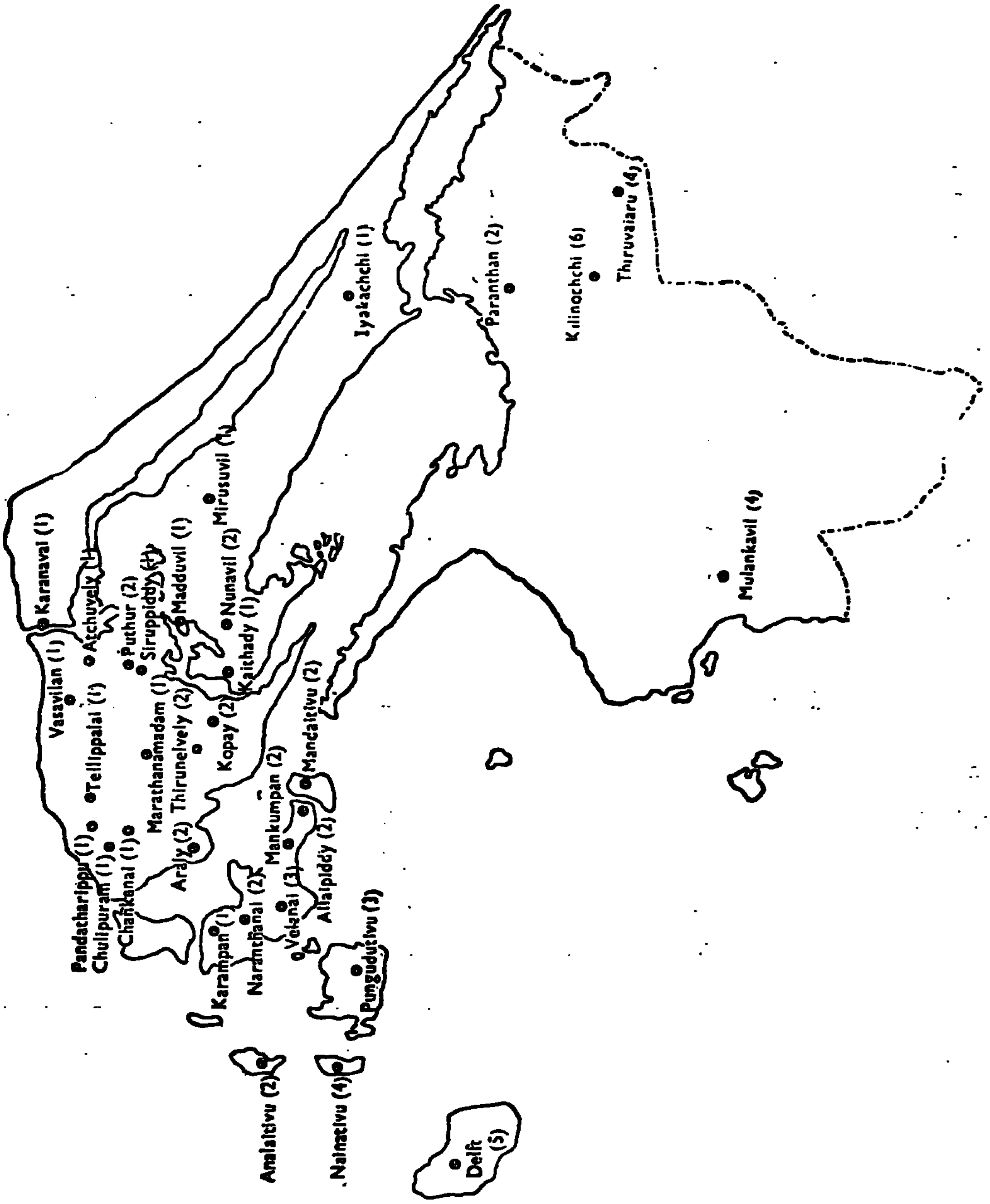

Fig. 1. Map of Jaffna and Kilinochchi districts showing sampling sites.
Figure within bracket refers to number of wells sampled at each site.