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Impact of agricultural activities on groundwater quality and its suitability for drinking in Valikamam area, Jaffna Peninsula

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ABSTRACT

Jaffna Peninsula is underlain mainly by Miocene limestone considered to be a good aquifer for groundwater storage and release. The Chunnakam aquifer in Valikamam area is the main limestone aquifer of Jaffna Peninsula. The objective of this study was to assess the impact of agricultural activities on groundwater quality in this study area. Groundwater samples were collected from forty fourwells to represent different uses such as domestic, domestic with home garden, public and farm wells and different cropping systems such as paddy, banana, high land crops and mixed crops. The data was for the period January to April 2011, whichrepresents a critical period covering the end of wet season to beginning of dry season. Important drinking water parameters, namely pH, electrical conductivity (EC), chloride, nitrate-N, fluoride, calcium, magnesium, carbonate, bicarbonate, sodium and potassium were determined to map the spatial variation of drinking water quality of the aquifer using GIS. Information on land use and agricultural practices such as fertilizer applicationand irrigation were obtained through a questionnaire survey and direct observations. High concentrations of nitrate–N, salinity development along coastal area and low levels of fluoride were the problems identified compared to Sri Lankan drinking water standards. The study showed that the level of nitrate-N concentration of water was influenced by different agronomic practices. Excessive irrigation and excessive application of nitrogen as inorganic fertilizer were found in the Valikamam area of the Chunnakam aquifer. Fertilizer application and irrigation practices were decided by the farmer based on their own experience and hardly any extension service exists to advise the farmer on these aspects. However, long-term monitoring is essential to make a firm conclusion and devise protective measures.

INTRODUCTION

The Jaffna Peninsula lies in the northern most part of Sri Lanka. It has four main types of aquifer systems, namely Chunnakam, Thenmaradchi, Vadamaradchi and Kayts (Punthakey and Nimal, 2006). Limestone is the main aquifer type in the Jaffna Peninsula. Groundwater is an extremely valuable resource in the Peninsula and pollution of groundwater is a matter for serious concern. Agriculture is the main source of livelihood for 65% of the population and about 34.2% of the land is cultivated intensively with high value cash crops such as red onion, chillies, potatoes, tobacco, vegetables, banana and grapes for commercial purposes (Thadchagini and Thiruchelvam, 2005).

In some parts, the density of wells was reported to be up to 75agricultural wells per 100 ha (Balendran et *al.,* 1968). Fertilizer and pesticide residues leached from agricultural fields often contribute significantly to groundwater pollution. The high nitrate levels recorded in well waters of the Peninsula's agricultural areas is very likely related to the intensive cultivation practiced in that region. Pollution of groundwater by nitrate has been receiving attention in the Peninsula since early 1980s (Maheswaran and Mahalingam, 1983; Dissanayake and Weerasooriya, 1985; Nagarajah *et al*., 1988; Maheswaran, 2003 &Mikunthan and Silva, 2008). Though many studies have been carried out on groundwater quality in the Peninsula, no systematic studies have been carried out so far to characterize the drinking water quality of aquifers in the Jaffna Peninsula. Hence, the objective of this study was to assess the impact of agriculturalactivities on groundwater quality and its suitability for drinking in Valikamam area, Jaffna Peninsula.

METHODS AND MATERIALS

Description of the study area

Jaffna Peninsula experiences the major rainy season during the North-East monsoon from October to December and the minor rainy season during the South-West monsoon in April and May (Mapa *et al*., 2010). The major soils in the Peninsula are the calcic red-yellow latosols which are shallow, fine textured and well-drained with very rapid infiltration rates (De Alwis and Panabokke, 1972).

Selection of wells

Forty four wells were selected for water quality monitoring in a systematic manner to represent the entire Chunnakam aquifer. Selected wells are under usages such as domestic, domestic and home gardening, public wells for drinking purpose and farm wells. Of the selected wells, twenty four (24) were farm wells from different cropping systems namely high land crops (chilly, onion, brinjal, and tobacco), mixed crops (high land crops with banana), banana and paddy.Figures 1 show the locations of the wells selected for monitoring.

Collection of water samples and analytical techniques

The data used in this study covered the period from January to April 2011 representing a critical period covering the end of wet season to beginning of dry season. Samples were analyzed for pH, Electrical Conductivity (EC), nitrate-N, fluoride, calcium, magnesium, chloride, carbonate, bicarbonate, sodium and potassium concentrations. The procedures of the analysis were based on Sri Lankan standard 614. Spatial distribution maps for different parameters were developed by ArcGIS 10 using IDW interpolation technique.

Field data collection

A questionnaire survey was carried out to collect information regarding cropping pattern and fertilizer usage in the study areas. Recommended rates of fertilizer for each crop were obtained from the fertilizer recommendation for horticultural crops - 2007, Department of Agriculture, Peradeniya. Rainfall data during the study period was obtained from the Meteorological Department, Thirunelveli.

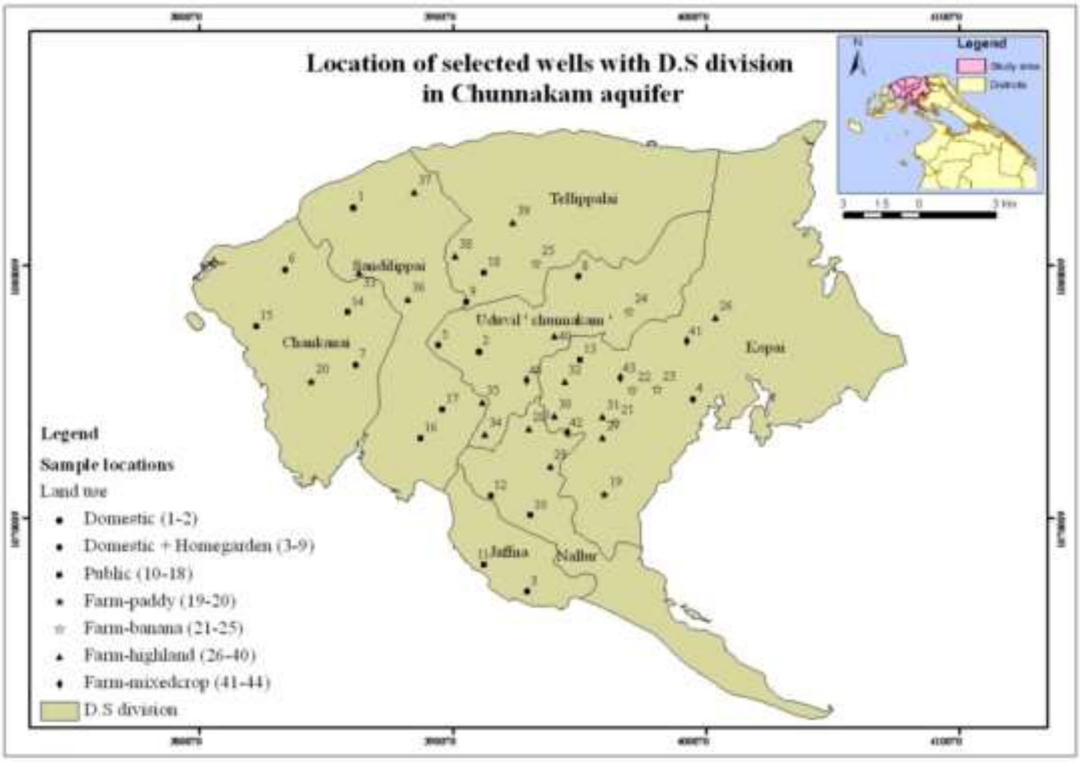


Figure 1 - Location of selected wells with DS divisions in Chunnakam aquifer

Calculation of crop water requirement

Environmental parameters required for the estimation of reference crop evapotranspiration, i.e., monthly average mean temperature, humidity, wind speed and sunshine hours, were obtained from the Meteorological Department, Thirunelveli.The type of crop, frequency of irrigation, rate of pumping and duration of pumping were obtained through direct observation during the questionnaire survey. Crop coefficients for required crops were taken from Allen et al. 1998. The time required to fill a 50 liter bucket was used to measure the rate of pumping during irrigation.The CROPWAT 8.0 decision support tool, developed by the Land and Water Development Division of the Food and Agriculture Organization of the United Nations (FAO), employing Penman-Montieth method was used to calculate the reference crop evapotranspiration (ETo) values. Crop evapotranspiration was calculated by multiplying the reference evapotranspiration by the respective crop co-efficient.

RESULTS AND DISCUSSION

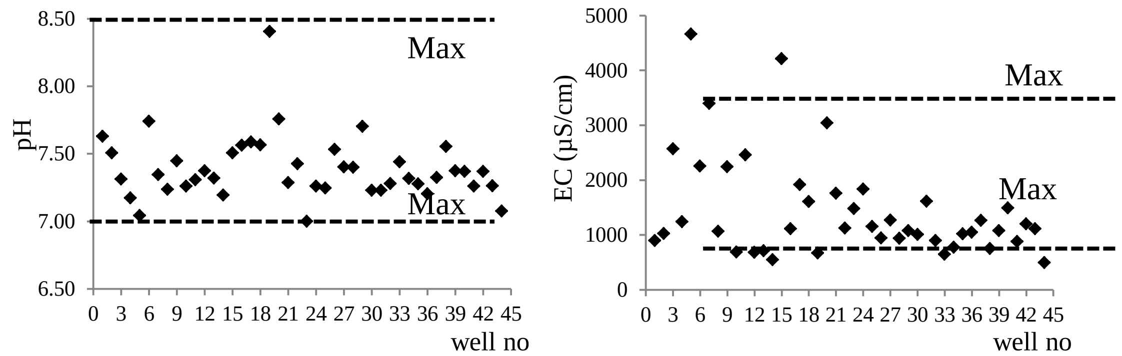
General

Size of the farm lands in the Chunakam aquifer area ranges form 0.1 – 1.5 ha. In intensified agricultural areas, farmers practice year round cultivation with no fallowing in between the cropping cycles. Pumping is done for approximately three hours on a daily basis or may be with two shifting. The depths of most of the wells are ranging from 2.5 m to 10 m. Most of the farmers have their own wells and in some cases a well is shared by three or four farmers. Timing of crop, irrigation, fertilizer application and all the cultivation practices are decided by the farmer with their experience.

Drinking water quality of selected wells

pH

The average pH values of water samples were within the range of 7.0 to 8.41 indicating a slight alkalinity (Figure 2a). Puvaneswaran (1986) and Rajasooriyar et al. (2002) reported that the pH value of water in the Jaffna Peninsula region is greater than 7.0. According to Sri Lankan Standard Institute (SLSI) guidelines, the desirable level of pH for drinking water could vary from 7.0 to 8.5. Thus, groundwater in the study area could be considered as being acceptable for drinking in this respect.

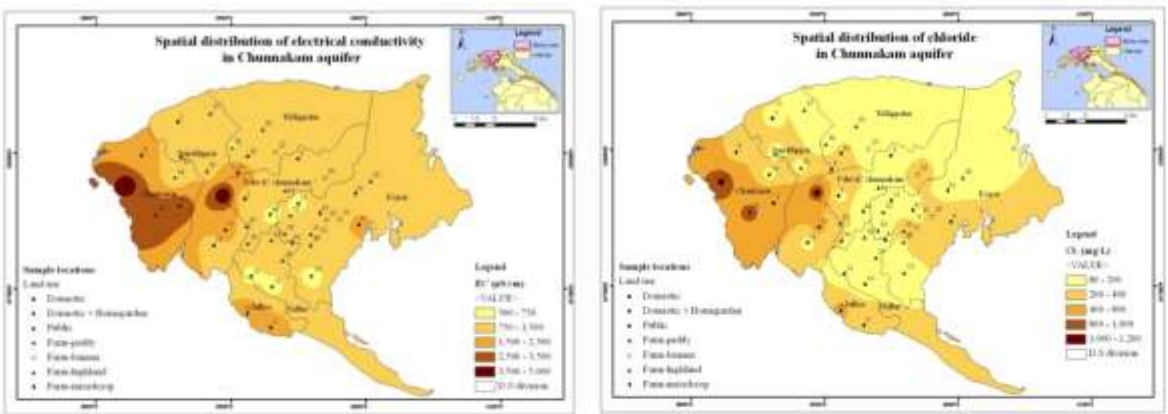


(a) (b)

Figure 2 - Average pH and EC

Electrical conductivity (EC)

The EC of the water samples is an indicator of their salinity. The average EC values ranged from 500 to 4660 µS/cm (Figure 2b). However, 95% of the wells were within the limits of SLSI permissible levels. As shown in Figure 3a, the groundwater of Chunnakam aquifer is characterized by the occurrence of high EC contents with widely differing concentrations among individual wells during March 2011. Higher EC was clearly shown to be more common closer to the coast, and decreasing inland. Well-5 and 15 had relatively high EC values of above 4000 µS/cm which was above the SLSI guideline for drinking water of 3500 µS/cm. The trend of EC generally reflects the chloride concentration available in groundwater and enriched by the discharge ions of sodium, calcium and magnesium(Jothivenkatachalam *et al*., 2011).



(a) (b)

Figure 3 - Spatial variation of EC and Cl^-

Chloride
The average chloride concentrations of water samples of all wells were between 80 mg/L to 1100 mg/L(Figure 4a). All values of measured wells were below the permissible level of SLSI guideline for drinking. The high chloride concentration of 1100 mg/L was observed in a public well (well-15 at Moolai) which is located closer to coastal line. Of the forty four wells measured, 66% showed chloride contents less than 200 mg/L and 34% were within the range of 200 mg/L to 1200 mg/L. High concentration of chloride was observed in well- 5 and 15. However, these two wells are still used for drinking purposes.

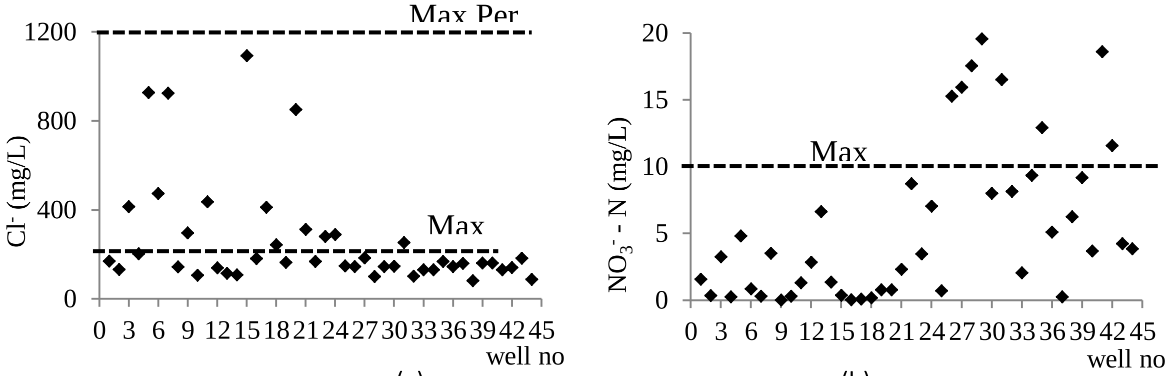


Figure 4 - Average Cl^- and NO_3^- as N

The spatial variation of chloride concentration during March in Chunnakam aquifer is shown in Figure 3b. High concentration of chloride was observed closer to the coast, and decreasing inland. The patterns of EC and chloride concentration are a clear indication of the influence of sea. Rajasooriyar et al., (2002) mentioned that high chloride concentration in some selected coastal locations provide evidence for seawater intrusion.

Nitrate–N
The average nitrate- N concentration ranged from undetermined value to 19.6 mg/L (Figure 4b). All domestic, domestic with home garden and public wells could be recommended for drinking as the average values of nitrate-N were below the SLSI guideline for drinking water. Among the selected farm wells, 31% exceeded the SLSI guideline of 10 mg/L and not suited for drinking. Gunasegaram (1983) studied extensively groundwater contamination in the Jaffna Peninsula and found that the nitrate levels exceeded standard limitsdue to the mixing up of abundant nitrogenous waste matter and synthetic and animal fertilizers reaching the shallow groundwater table. Mageswaran and Mahalingam (1983) also reported high nitrate-N content in the well water and soil.However, the violent conflict that lasted for more than 25 years after this period could have reduced the intensity of agriculture in these areas and stabilized or reduced the nitrate-N concentrations.

Nitrate as N content was below 10 mg/L in January, March and April in domestic, domestic with home garden and private wells and did not have the problem of nitrate for drinking purpose. Figure 5 shows temporal fluctuation of nitrate-N concentration in groundwater in different agricultural land uses such as paddy, banana, highland crops and mixed crop. Groundwater within the intensively cultivated area had nitrate-N concentrations in between undetermined value to 35 mg/L. High nitrate –N concentration of ground water was observed at high land crop land use and followed by mixed crops during January. Concentration of nitrate-N in paddy and banana land use had less than the SLSI guideline for drinking water. The high nitrate- N value of 35mg/L was observed during January at Thirunelvely and Neervely which are highland and mixed crop respectively. Even though these wells are used for agricultural purpose, people who are working in the field use the well water for drinking. Jeyaruba and Thushyanthy (2009) also noted that the level of nitrate-N concentration of water was influenced by cropping systems.Cultivation of banana is normally under basin irrigation with organic fertilizers. Premanandarajah *et al.* (2003) mentioned that the addition of organic manure increases nitrogen retentions capacity and reduces nitrate loss by leaching in sandy soils. Since nitrogen retention increases with organic fertilizers, this could reduce leaching of nitrate-N to groundwater in banana land use. Hence one of the ways to reduce nitrate pollution of groundwater is by incorporating organic manures.

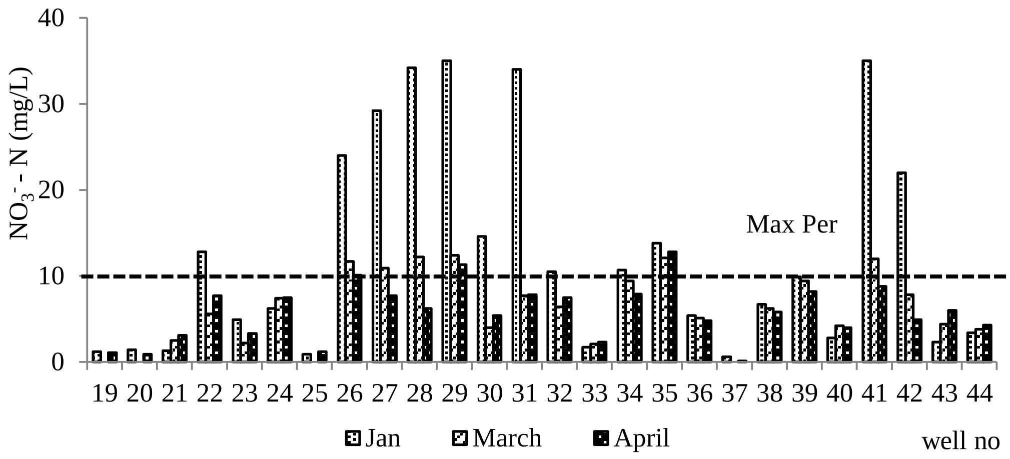
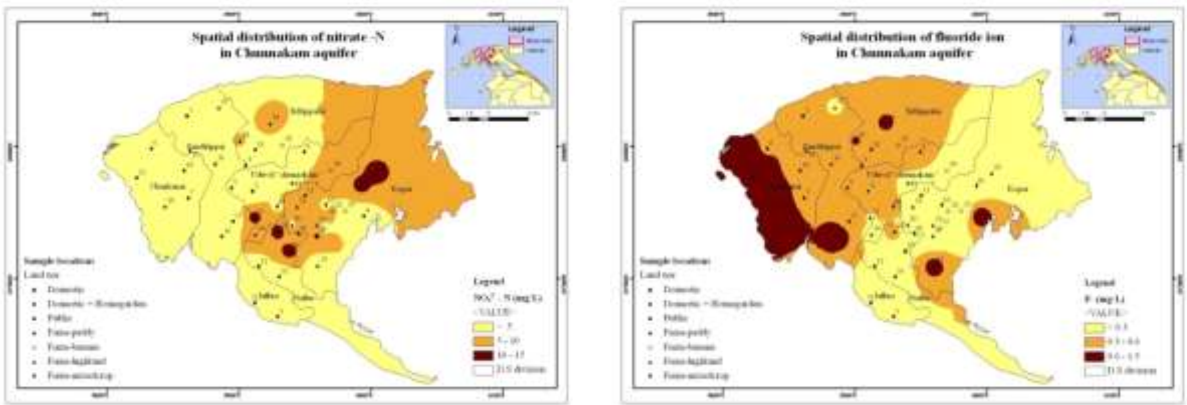


Figure 5 - Temporal fluctuation of NO_3- as N in farm wells

A general decreasing trend in nitrate-N concentration was observed from January to March. During rainy season, the soil is wetted enough up to the water table to facilitate the leaching of nitrate. In addition the Peninsula experienced heavy rainfall during *Maha* 2010 which resulted in high groundwater table in January. This in turn would have resulted in dissolving nitrate-N that was accumulated in the upper soil layers. Nandasena *et al.* (2005) reported that the rainfall influences the distribution of nitrate-N in the groundwater by raising or lowering of the groundwater table.



(a) (b)

Figure 6 - Spatial variation of NO_3^- as N and Fluoride ion

Spatial variation of nitrate-N concentration in Chunnakam aquifer during March 2011 is shown in Figure 6a. Here 14% of the wells were above acceptable level of SLSI guideline for drinking. These farm wells come under intensified agricultural area. Of these farm wells, well 26, 27, 35 and 39 are used for drinking purposes by farmers. Dissanayake and Weerasooriya (1985) pointed out that Jaffna Peninsula has the highest nitrate content among the groundwater of Sri Lanka. They also mentioned that the major factors responsible for the poor water quality in the Jaffna Peninsula are abundant use of agricultural fertilizers mainly urea, usage of cattle manure and discharge of human excreta in the form of soakage pit.

Fluoride

The average concentration of fluoride changed from un-determined value to 0.74 mg/L(Figure 7). Results revealed that 95% of the wells including domestic wells had water with less than 0.6 mg/L which could lead to deficiency of fluoride. The recommended level of SLSI guideline for fluoride in drinking water is 0.6 mg/L to 1.5 mg/L. Rajasooriyar *et al*., 2002 stated that fluoride concentrations in 95% of the wells from Valigamam region were less than 1 mg/L due to the result of solubility which controls causing calcium fluoride precipitation. The spatial variation of fluoride concentration in Chunnakam aquifer is shown in Figure 6b.

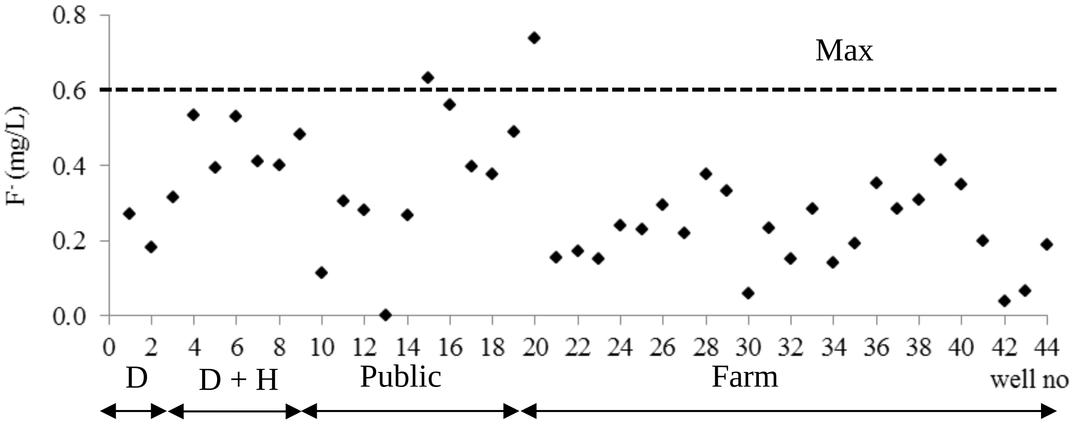
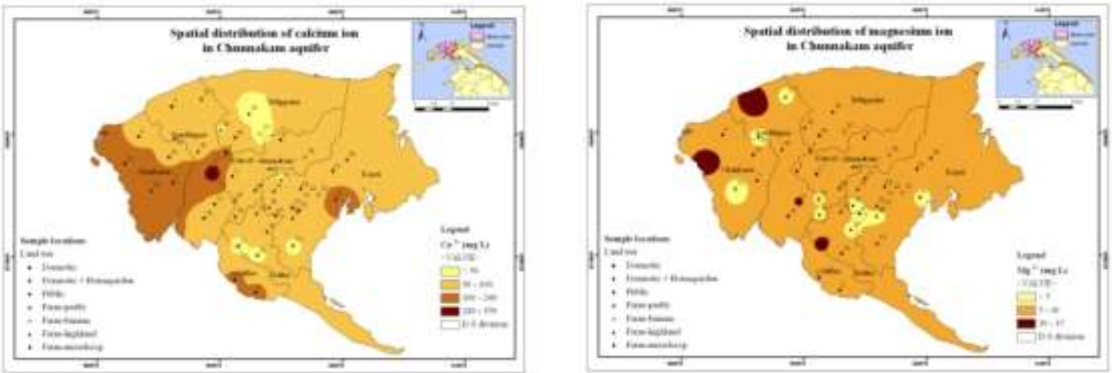


Figure 7 - Average concentration of fluoride ion

Calcium and Magnesium

The average calcium concentration varied from 50 to 340 mg/L. Based on average calcium concentration, 98% of the measured wells were below the SLSI guideline of 240 mg/L for drinking. The distribution of average concentration of magnesium in the studied area ranges from 5 to 25 mg/L. Figures 8a and 8b shows the spatial variation of calcium and magnesium ions during March 2011 in Chunnakam aquifer, respectively. The higher values of calcium by the end of wet season are observed near the coastal regions. The spatial variation of magnesium ion during March showed that all measured wells were below the SLSI guideline for drinking (140 mg/L).

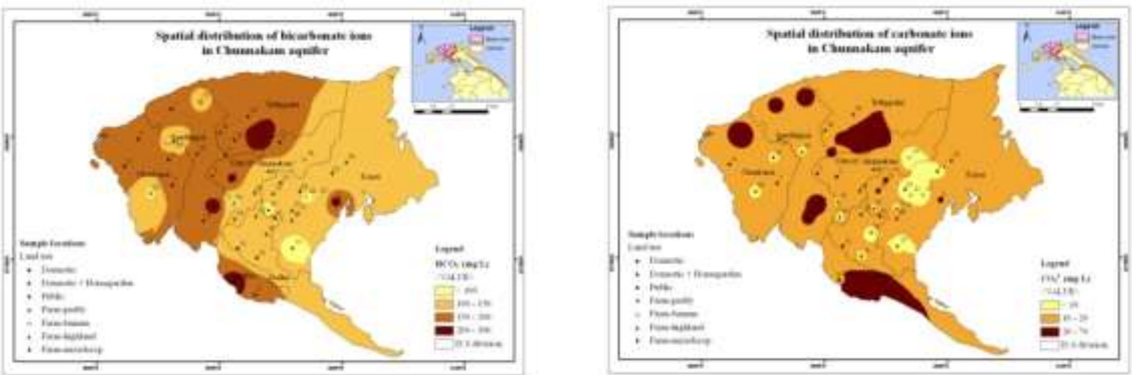


(a) (b)

Figure 8 - Spatial variation of Calcium and Magnesium ions

Bicarbonate and Carbonate

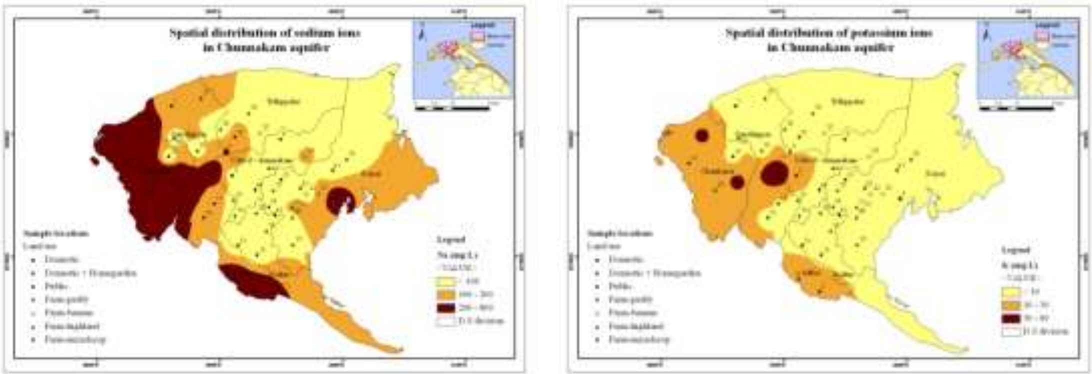
The average concentration of bicarbonate and carbonate values of selected wells varied from 100 mg/L to 350 mg/L and from 3 mg/L to 52 mg/L, respectively. The spatial variations of bicarbonate and carbonate for the selected wells during March were shown in Figures9a and 9b, respectively. Limestone aquifer is rich in carbonates. Hence waters flowing through limestone bring the carbonate to the groundwater which increases the alkalinity. Highly alkaline waters are unpalatable and may force consumers to seek other water sources.



(a) (b)

Figure 9 - Spatial variation of bicarbonate and carbonate ions

Sodium and Potassium
The distribution of average concentration of sodium and potassium in the studied area ranges from 20 mg/L to 740 mg/L and from 0.5 to 112 mg/L. The spatial variations of sodium and potassium for the selected wells during March 2011 are shown in Figure10a and 10b, respectively. No health-based guideline value is proposed, however, sodium may affect the taste of drinking water at levels above about 200 mg/l (WHO 2011). The higher values of sodium are observed near the coastal regions of Chunnakam aquifer and could be related to seawater intrusion. The above result is similar to the spatial distribution of EC and chloride (Figure 3a and 3b).



(a) (b)

Figure 10 - Spatial variation of sodium and potassium ions

Crop Water Requirements (CWR) and Water Use
At the time of the study (March 2011), banana, cassava and cabbage were already established in the field. Tobacco and onion were found in late stages. No rainfall was obtained during the month of March 2011 in Jaffna Peninsula. Therefore, irrigation water is the only source for crop.Average depth of irrigation water (mm/day) was calculated for each crop and compared with the CWR. Based on this analysis, the amount of irrigation water applied by farmers was higher than CWR for each crop. Hence excess irrigation which ranged from 5.33 - 10.89 mm/day was found in Valikamam area in Jaffna Peninsula. This amounts to 131 to 229% application in excesses of the net water requirement.

Application of Nitrogen as inorganic fertilizer
From the questionnaire survey, the amount of nitrogen applied as inorganic fertilizer (mainly urea) for onion, carrot, cabbage, beetroot and tobacco were calculated. Application of excess nitrogen (kg/ha) was calculated from different between the average amount of nitrogen applied by farmer and the recommendation of nitrogen (kg/ha) for each crop except tobacco. Table 1 shows the excess amount of nitrogen application for each crop in the studied area.

Table 1 - Excess amount of nitrogen application for each crop

Crop	Avg. nitrogen Applied (kg/ha)	Recommended nitrogen (kg/ ha)	Excess nitrogen (kg/ha)
Onion	178.1	70	108.1
Carrot	230	150	80.0
Cabbage	142.6	150	-7.4
Beetroot	246	180	66.0
Tobacco	262.9	No recommendation	-

Based on this study excess amount of nitrogen as inorganic fertilizer was applied for onion, carrot and beetroot. Application of nitrogen was lower than recommended level for cabbage. Department of Agriculture, Peradeniya has no fertilizer recommendation for tobacco. Inorganic fertilizer application practices were decided by the farmers by themselves with their own experience. In addition to the inorganic fertilizer, farmers have been using organic materials such as biomass and cattle and goat excreta which are rich in nitrogen. Leachate of nitrate-N from these sources could have accumulated in these wells.Farmers have the practice of keeping cattle and goat in the field during off season. 66.7% of the farmers practiced paddock system with cattle's ranging from 1- 30. The excreta and urine of animals gets incorporated in the field thus resulting in high nitrate-N in soil.

Based on analysis of CWR and amount of nitrogen application for each crop, it can be concluded that the use of large quantities of inorganic fertilizers and manure together with excessive irrigation were considered to be responsible for the high nitrate content. In a survey carried out in 1982, three-quarters of the wells sampled had a concentration in excess of recommended guideline value of 50 mg/L nitrate and some were in excess of 175 mg/L nitrate (Nagarajah *et* *al*., 1988). The study area contains red yellow latosol which is highly porous and having an infiltration rate of 430 mm/h conducive for the free leaching of nutrients to the shallow groundwater (Joshua, 1973).

CONCLUSION

High concentrations of nitrate–N and EC and low levels of fluoride were the identified drinking water problems in the study area. The level of nitrate-N concentration of water was influenced by cropping system as high nitrate-N concentration of groundwater was observed at high land crops land use followed by mixed crops when compared to banana and paddy.Based on this study excess irrigation and excess amount of nitrogen as inorganic fertilizer application were found at Valikamam area of Chunnakam aquifer in Jaffna Peninsula.Therefore, awareness should be created on the hazards due to the excessive use of chemical fertilizers in agriculture. Recommendations should be made based on continuous monitoring.

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